Water Year 2007
Overview of Surface Water Monitoring Data for SC, SAR and Flow in the Tongue River Watershed

This cover photo shows the Tongue River at the Tongue River Dam looking upstream from the gaging station. Photo from USGS website http://tongueriverm onitoring.cr.usgs.gov/photos/photoindex.htm

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Introduction

When Coal Bed Natural Gas (CBNG) is developed, the methane must be allowed to desorb from the coal so that it can flow to production wells. This desorption is typically achieved by pumping groundwater (referred to as CBNG water) from the coal bed aquifer to reduce the hydrostatic pressure within the coal seam (allowing the methane to desorb) and create a pressure gradient within the aquifer. This pressure gradient causes methane to flow towards the pumping wells.

CBNG water in the Montana portion of the Powder River Structural Basin (PRB) is moderately saline, having a Specific Conductance (SC) on the order of 2,000 microSiemens per centimeter at 25 degrees Celsius (μS/cm). SC is the ability for water to conduct an electrical current at 25 degrees Celsius, and it is proportional to salinity (concentration of major ions, or salts). High salinity irrigation water may result in decreased crop yields depending on the crop being grown (See Fig. 1). The technical definition of Electrical Conductivity EC is "the ability of water to conduct a current"; however the Montana Department of Environmental Quality (MDEQ) regulations define EC as "the ability of water to conduct an electrical current at 25ºC". Since the EC definition is the same as the technical definition of SC, the SC values discussed in this report are directly comparable to the MDEQ's EC standards.

CBNG water in Montana is a sodium-bicarbonate (Na-HCO_3) type water, while the Tongue River mainstem is more balanced; having Ca>Mg>Na. Because there is little sulfate in water from productive coal seams (VanVoast, 2003), bicarbonate is the predominant anion in CBNG water (HCO_3>SO_4), as well as in the Tongue River (See Fig. 2). The dominance of sodium cations in CBNG water results in a high Sodium Adsorption Ratio (SAR; which is a complex ratio of Na to Ca+Mg) that typically ranges between 30 and 60 (ALL, 2001). Irrigation water with high SAR values may cause impacts to soil structure, and impair the ability for clay rich soils to infiltrate water (see Fig. 3). Some of the CBNG produced water in the PRB is managed through treated or untreated discharge to surface waters under National Pollutant Discharge Elimination System (NPDES) permits, implemented under the Clean Water Act.

In Montana, NPDES discharge permitting is conducted by the Montana Department of Environmental Quality (MDEQ) under the Montana Pollutant Discharge Elimination System (MPDES) permit program. During Water Year 2007 (10/1/06 to 9/30/07), three CBNG MPDES permits were in use. One permit (Fidelity's MT0030457) allows for the discharge between 1,600 and 2,500 gallons per minute (gpm) of untreated water into the Tongue River, with the rate varying by season. This permit has been in use since September 1999 and the most recent modification took effect on April 1, 2006. Fidelity also has a MPDES permit for treated discharge into the Tongue River (MT0030724); this permit became active April 1, 2006. Fidelity's treated water permit allows for the discharge of 1,700 gpm year round; however the quality of the water allowed to be discharged varies by season. The final MPDES permit (Pinnacle Gas Resources' (PGR) MT0030660) allows for the discharge to the Tongue River of up to 1,122 gpm of treated CBNG water, with SAR < 3 and EC < 1000 μS/cm.

In Wyoming, NPDES discharge permitting is conducted by the Wyoming Department of Environmental Quality (WDEQ) under the Wyoming Pollutant Discharge Elimination System (WYPDES) permit program. Within Wyoming, two permits were originally issued in 1999 allowing for the direct discharge of untreated CBNG water to surface waters in the Tongue River watershed. Both permits were renewed in April, 2004. Currently, these permits authorize the discharge of 135 gpm from 11 discharge points to Goose Creek, and 40 gpm from three discharge points to the Tongue River. More recently, the "Brinkerhoff" permits were issued in the Prairie Dog Creek watershed for discharge of untreated water into impoundments. A permit for the discharge of treated water into Prairie Dog Creek has also been approved by the WDEQ. This permit, establishes a dissolved sodium effluent limit of 50 milligrams per liter (mg/L) and an EC effluent limit of 1000 μS/cm. Within the Wyoming portion of Hanging Woman Creek there is a WYPDES permit for the discharge of untreated CBNG water to 13 off-channel impoundments (WY0053023), and a WPDES permit for the discharge of untreated CBNG water to one on-channel impoundment (WY0052407).

Several other factors have potential impacts on the Tongue River system. The Decker Coal mines near Decker, MT, discharge excess water from pit dewatering into the Tongue River Reservoir under MPDES

permits. The Tongue River Reservoir reduces the variability in flow and water quality downstream of it. Irrigation withdrawals and return flows occur along the entire length of the river. The TY diversion dam near Miles City diverts a significant portion of the water in the river during low flow periods.

In response to the potential for CBNG development in this area, the MDEQ and Northern Cheyenne Tribe have each developed surface water quality standards for EC and SAR in the Tongue River watershed. These standards provide criteria against which to compare the monitoring data. These standards are summarized in Table 1 below. It should be noted that the MDEQ standards have been reviewed and approved by the United States Environmental Protection Agency (EPA), and therefore have Clean Water Act standing. The Northern Cheyenne Tribe has been granted "Treatment as a State" (TAS) status by the EPA; however their standards have not been approved by the EPA. Thus, the Northern Cheyenne standards do not have Clean Water Act standing. Also, note that irrigation season standards are different from the non-irrigation season, and the MDEQ and Northern Cheyenne have defined the irrigation season differently. The irrigation season standards developed by the MDEQ are applicable year-round to the Tongue River above the Tongue River Dam. MDEQ standards are applicable at the Wyoming-Montana state line; however they are not applicable in Wyoming.

TABLE 1: MDEQ and Northern Cheyenne Surface Water Standards Applicable for Water Year 2007 for EC and SAR in the Tongue River Watershed (from MDEQ, 2003a and Greystone and ALL, 2003)

Irrigation Season[1]						
	MDEQ			Northern Cheyenne		
	Tongue River	Tributaries	Tongue River Reservoir	Tongue River Southern Boundary	Tongue River Northern Boundary	Tributaries
EC (µS/cm) Mean Monthly	1000	500	1000	1000	1500	1500
Not to Exceed	1500	500	1500	2000	2000	2000
SAR Mean Monthly	3.0	3.0	3.0	---	---	---
Not to Exceed	4.5	4.5	4.5	2.0	3.0	3.0

Non-Irrigation Season[1]						
	MDEQ			Northern Cheyenne		
	Tongue River	Tributaries	Tongue River Reservoir	Tongue River Southern Boundary	Tongue River Northern Boundary	Tributaries
EC (µS/cm) Mean Monthly	1500	500	1000	---	---	---
Not to Exceed	2500	500	1500	2000	2000	2000
SAR Mean Monthly	5.0	5.0	3.0	---	---	---
Not to Exceed	7.5	7.5	4.5	2.0	3.0	3.0

1: The Irrigation Season specified by the MDEQ is from March 1st to October 31st while the Irrigation Season specified by the Northern Cheyenne is from April 1st to November 15th.

During Water Year 2007, the Montana Board of Environmental Review (BER) modified the standards which apply to CBNG in Montana. The most substantial change adopted by the BER was to designate EC and SAR "harmful" parameters. This change has been approved by the EPA, and is in force at this time. This designation requires an "authorization to degrade" if a new or increased discharge

would cause an increase in the concentration of a harmful parameter which was already above 40% of the standard. Within the Tongue River watershed historical water quality values are rarely less than these 40% criteria.

For fiscal year 2007, the U.S. Geological Survey (USGS) attained funding to conduct surface-water-quality monitoring in the Tongue River watershed to collect and disseminate data to stakeholders and the general public, as well as to State and Federal agencies tasked with managing and regulating CBNG development. Since this congressional funding was not sufficient to fully fund this network, the US Bureau of Land Management (BLM), MDEQ, WDEQ, Wyoming State Engineer's Office (WSEO), Montana Department of Natural Resource Conservation (MDNRC), T & Y Irrigation District, and the Northern Cheyenne Tribe also provided funding for this network (See Map 1).

During water year 2007, SC and flow were measured and SAR was estimated by the USGS in real time for some stations; SC and SAR data were available seasonally for most sites (about March-October to provide data for the irrigation season). In this report the daily mean values for SC and daily mean estimated SAR values are used. Some of these data are considered provisional by the USGS because they were retrieved from the USGS web site prior to final USGS approval. Final values may be slightly different due to revisions made during final quality-assurance and review. SAR was estimated at some stations from the relationship between SC and SAR. The estimation procedure is discussed in detail at http://tonguerivermonitoring.cr.usgs.gov/index.htm and in the report by Cannon and others (2007). At some sites, the relationship between SC and SAR was not sufficiently robust to provide a reliable estimation of SAR, and so SAR was not estimated.

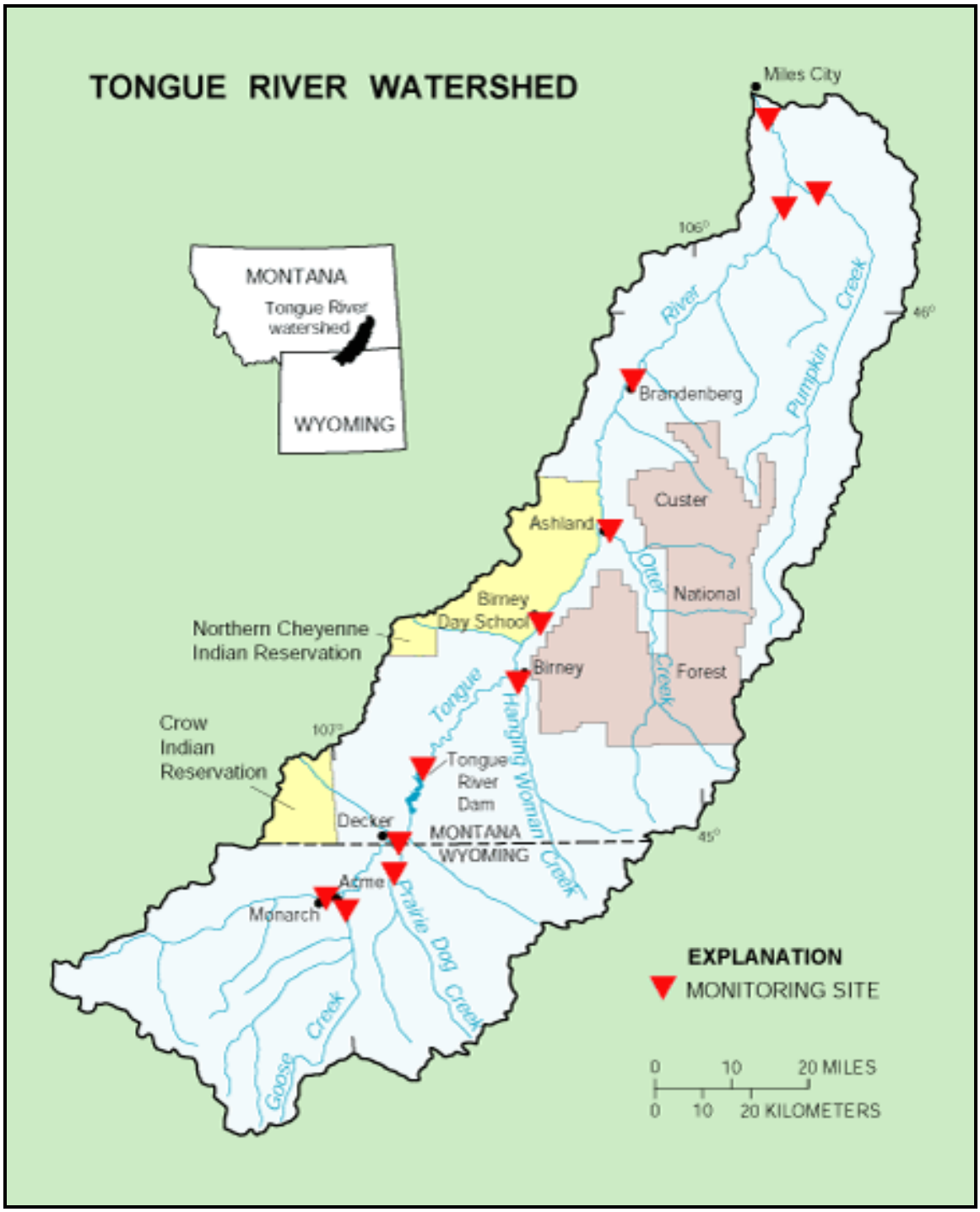
It is important to note that estimated SAR values are provided as an indication of the general magnitude and relative increase or decrease of values as an aid for assessing current conditions. Estimated SAR values are approximate and are not intended to be used for determination of compliance with water-quality standards. They can be used for general summaries to make comparisons between sites or to indicate conditions of elevated values relative to standards, but assessments of actual compliance with standards are only applicable to analytical results for samples.

Surface water-quality samples were also obtained periodically under this program. Although these samples were analyzed by the USGS for many parameters, this report will focus on SC and SAR, along with their relation to flow conditions. SC and SAR are considered to be the parameters most likely to be affected by CBNG development (MDEQ, 2003b), and SC and SAR in the natural system fluctuate significantly with flow. An expanded set of analytical data and additional information about this network are available from the USGS Tongue River project website at http://tonguerivermonitoring.cr.usgs.gov/index.htm.

Data Review

For all sites, please see the figures section for graphical display of the data. Complete data sets can be obtained at http://tonguerivermonitoring.cr.usgs.gov/index.htm.

For each station a summary of the daily mean flow and daily mean SC recorded by continuous monitors, along with daily mean estimated SAR data during water year 2007 are presented. Analytical results for SC and SAR measured from periodically-collected water-quality samples are also presented. Comparisons are made to the MDEQ and Northern Cheyenne surface water standards for EC and SAR where they are applicable. For comparison to the Mean Monthly EC and SAR standards, the Mean Monthly values are calculated as the simple average of all the daily mean values and analytical results for each calendar month, so long as at least nine values were available. Note that within the figures section, the daily mean and analytical data are combined when discussing the range of measured values. SC vs. Flow, SAR vs. Flow, and SC vs. SAR with historical data are presented in graphical form to allow evaluation of 2007 data in context.



Map 1 shows the Tongue River Watershed as it extends from Wyoming into Montana. Also shown are major streams, and major land-ownership patterns (USFS, Northern Cheyenne Reservation, and Crow Reservation). The locations of the 12 surface water monitoring sites (3 in Wyoming, 9 in Montana), which are the subject of this report, are also shown. Figure obtained from http://tongueriver monitoring.cr.usgs.gov/index.htm

Main Stem Sites

Tongue River at Monarch, WY

Table 2: Summary of USGS Monitoring Data
Tongue River at Monarch (station 06299980)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	56	47
		Max	2720	112
	SC (uS/cm)	Min	169	---
		Max	565	---
	Estimated SAR	Min	0.1	---
		Max	0.5	---
Analytical Values	SC (uS/cm)	Min	190	416
		Max	532	470
	SAR	Min	0.2	0.3
		Max	0.7	0.4
Mean Monthly*	SC (uS/cm)	Min	221	---
		Max	453	---
	SAR	Min	0.2	---
		Max	0.4	---

* Mean Monthly Values are calculated by taking the simple mean of all daily mean and analytical samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. There are no CBNG discharges upstream of this station. Some irrigation diversion/return flow occurs upstream of this station.

Daily mean flow values ranged from 56 to 2720 cfs, with the mean being 301 cfs. These flows are 168% of historical (2004-2007) (see Fig. 4).

Daily mean SC data recorded at this station ranged from 169 to 565 µS/cm. Daily mean estimated SAR at this station ranged from 0.1 to 0.5. Analytical SC values at this site ranged from 190 to 532 µS/cm. Analytical SAR values at this site ranged from 0.2 to 0.7. Mean Monthly SC values ranged from 221 to 453 µS/cm. Mean Monthly estimated SAR values ranged from 0.2 to 0.4 (see Fig. 5).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 6-8).

Tongue River at State Line, near Decker, MT

Table 3: Summary of USGS Monitoring Data
Tongue River at State Line (station 06306300)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	90	70
		Max	5530	203
	SC (uS/cm)	Min	212	596
		Max	873	924
	Estimated SAR	Min	0.3	0.7
		Max	1.3	1.4
Analytical Values	SC (uS/cm)	Min	253	640
		Max	824	710
	SAR	Min	0.3	0.7
		Max	1.1	0.8
Mean Monthly*	SC (uS/cm)	Min	297	672
		Max	705	707
	SAR	Min	0.4	0.8
		Max	0.9	0.9

* Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Wyoming CBNG discharges, some of Fidelity's CBNG discharges in Montana, and irrigation diversions/return flows occur upstream from this station.

Daily mean flow values for water year 2007 ranged from 70 to 5530 cfs, with the mean being 540 cfs. These flows are 125% of historical (1960-2006) (see Fig. 9). The flows observed here are substantially greater than those seen at Monarch due to the addition of Goose Creek, Prairie Dog Creek, and other minor tributaries (See Map 1).

Daily mean SC data recorded at this station ranged from 212 to 924 µS/cm. Daily mean estimated SAR at this station ranged from 0.3 to 1.4. Analytical SC values at this site ranged from 253 to 824 µS/cm. Analytical SAR values at this site ranged from 0.3 to 1.1. Mean Monthly SC values ranged from 297 to 707 µS/cm. Mean Monthly estimated SAR values ranged from 0.4 to 0.9. All SC and SAR values measured or estimated at this station were below the applicable MDEQ Standards (see Fig. 10). Note that irrigation season standards apply year-round upstream of the reservoir.

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 11-13).

Tongue River below Tongue River Dam, near Decker MT

Table 4: Summary of USGS Monitoring Data
Tongue River below Dam (station 06307500)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	58	81
		Max	4370	159
	SC (uS/cm)	Min	217	600
		Max	770	751
	Estimated SAR	Min	0.3	0.9
		Max	1.1	1.1
Analytical Values	SC (uS/cm)	Min	321	636
		Max	765	760
	SAR	Min	0.4	1.2
		Max	1.2	1.3
Mean Monthly*	SC (uS/cm)	Min	296	621
		Max	739	741
	SAR	Min	0.4	0.9
		Max	1.1	1.1

* Mean Monthly Values are calculated by taking the simple mean of all daily mean and analytical samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtiime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Wyoming CBNG discharges, Fidelity's CBNG discharges, irrigation diversions/return flows, the Tongue River Reservoir, and the Decker Coal Mines occur upstream from this station. The PGR's CBNG discharge is located just downstream from this location.

Daily mean flow values ranged from 58 to 4370 cfs, with the mean being 526 cfs. These flows are 123% of historical (1939-2006) (see Fig. 14). Flows at this station are regulated by Tongue River Dam operations (See Map 1).

Daily mean SC data recorded at this station ranged from 217 to 770 µS/cm. Analytical SC values for samples collected at this site ranged from 321 to 765 µS/cm. Daily mean estimated SAR ranged from 0.3 to 1.1. Analytical SAR values at this site ranged from 0.4 to 1.3. Mean Monthly SC values ranged from 296 to 741 µS/cm. Mean Monthly SAR values ranged from 0.4 to 1.1. All SC and SAR values measured or estimated at this station were below the applicable MDEQ Standards (see Fig. 15).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 16-18).

Tongue River at Birney Day School Bridge, near Birney, MT

Table 5: Summary of USGS Monitoring Data
Tongue River at Birney Day School (station 06307616)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	59	80
		Max	4670	162
	SC (uS/cm)	Min	327	---
		Max	755	---
	Estimated SAR	Min	0.5	0.98
		Max	1.2	1.01
Analytical Values	SC (uS/cm)	Min	337	670
		Max	715	789
	SAR	Min	0.5	1.2
		Max	1.4	1.3
Mean Monthly*	SC (uS/cm)	Min	350	---
		Max	721	---
	SAR	Min	0.5	---
		Max	1.1	---

* Mean Monthly Values are calculated by taking the simple mean of all daily mean and analytical samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Wyoming CBNG discharges, Fidelity's CBNG discharges, the Decker Coal Mines, the Tongue River Dam, PGR's CBNG discharges, and irrigation diversions/return flows occur upstream from this station.

Mean daily flows ranged from 59 to 4670 cfs, with the mean being 515 cfs. These flows are 142% of historical (1979-2006) (see Fig. 19). Flows at this station are regulated by Tongue River Dam operations.

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 327 to 755 µS/cm. Analytical SC values at this site ranged from 337 to 789 µS/cm. Daily mean estimated SAR during the seasonal period of operation ranged from 0.5 to 1.1. Analytical SAR values at this site ranged from 0.5 to 1.4. Mean Monthly SC values ranged from 350 to 721 µS/cm. Mean Monthly estimated SAR values ranged from 0.5 to 1.1. All SC and SAR values measured or estimated were below the applicable MDEQ and Northern Cheyenne Standards for this site (see Fig. 20).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 21-23).

Tongue River below Brandenberg Bridge, near Ashland, MT

Table 6: Summary of USGS Monitoring Data
Tongue River at Brandenburg Bridge (station 06307830)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	58	80
		Max	3460	146
	SC (uS/cm)	Min	362	---
		Max	841	---
	Estimated SAR	Min	0.6	---
		Max	1.5	---
Analytical Values	SC (uS/cm)	Min	380	692
		Max	823	860
	SAR	Min	0.6	1.4
		Max	1.7	1.5
Mean Monthly*	SC (uS/cm)	Min	413	---
		Max	743	---
	SAR	Min	0.7	---
		Max	1.3	---

* Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Wyoming CBNG discharges, Fidelity's CBNG discharges, the Decker Coal Mines, the Tongue River Dam, PGR' CBNG discharges, and irrigation diversions/return flows occur upstream from this station.

Daily mean flows during Water Year 2007 ranged from 58 to 3460 cfs, with the mean being 507 cfs. These flows are 126% of historical (1973-2006) (see Fig. 24). Flows at this station are affected by regulation by Tongue River Dam operations.

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 362 to 841 μS/cm. Analytical SC values at this site ranged from 380 to 860 μS/cm. Daily mean estimated SAR at this station ranged from 0.6 to 1.5. Analytical SAR values at this site ranged from 0.6 to 1.7. Mean Monthly SC values ranged from 413 to 743 μS/cm. Mean Monthly SAR values ranged from 0.7 to 1.3. All SC and SAR values measured or estimated were below the applicable MDEQ and Northern Cheyenne Standards for this site (see Fig. 25).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 26-28).

Tongue River above TY Diversion

Table 7: Summary of USGS Monitoring Data
Tongue River above TY Diversion (station 06307990)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	55	40
		Max	5460	156
	SC (uS/cm)	Min	424	786
		Max	946	833
	Estimated SAR	Min	0.7	1.6
		Max	2.0	1.7
Analytical Values	SC (uS/cm)	Min	390	523
		Max	886	998
	SAR	Min	0.7	1.4
		Max	2.1	1.8
Mean Monthly*	SC (uS/cm)	Min	451	805
		Max	853	805
	SAR	Min	0.8	1.6
		Max	1.7	1.6

* Mean Monthly Values are calculated by taking the simple mean of all daily mean and analytical samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Wyoming CBNG discharges, Fidelity's CBNG discharges, the Decker Coal Mines, the Tongue River Dam, PGR's CBNG discharges, and irrigation diversions/return flows occur upstream from this station.

Daily mean flows ranged from 40 to 5460 cfs, with the mean being 522 cfs. These flows are 203% of historical (2004-2006) (see Fig. 29). Flows at this station are affected by regulation by Tongue River Dam operations.

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 424 to 946 µS/cm. Analytical SC values at this site ranged from 390 to 998 µS/cm. Daily mean estimated SAR ranged from 0.7 to 1.6. Analytical SAR values at this site ranged from 0.7 to 2.1. Mean Monthly SC values ranged from 451 to 853 µS/cm. Mean Monthly SAR ranged from 0.8 to 1.7. All SC and SAR values measured or estimated were below the applicable MDEQ Standards for this site (see Fig. 30).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 31-33).

Tongue River at Miles City, MT

Table 8: Summary of USGS Monitoring Data
Tongue River at Miles City (station 06308500)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	48	40
		Max	6130	400
	SC (uS/cm)	Min	412	---
		Max	1100	---
	Estimated SAR	Min	0.8	---
		Max	2.5	---
Analytical Values	SC (uS/cm)	Min	406	342
		Max	966	1140
	SAR	Min	0.8	1.8
		Max	2.5	2.1
Mean Monthly*	SC (uS/cm)	Min	452	---
		Max	915	---
	SAR	Min	0.9	---
		Max	2.1	---

*Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Wyoming CBNG discharges Fidelity's CBNG discharges, the Decker Coal Mines, the Tongue River Dam, PGR' CBNG discharges, irrigation diversions/return flows, and the TY Diversion dam occur upstream from this station.

The portion of the Tongue River immediately upstream from this station (from the TY diversion dam just above Pumpkin Creek to the mouth) is listed on the MDEQ's current (2006) 303(d) list as being a Category 4C stream segment. A 4C segment is considered to be impaired; however TMDLs are not required since no pollutant-related use impairment has been identified. For this section of the Tongue River the cause of impairment is "Low Flow Alteration", and the identified probable sources are "Dam Construction (Other than Upstream Flood Control Projects)" and "Impacts from Hydrostructure Flow Regulation/modification". As such it appears that this impairment is primarily due to diversion of water at the TY diversion dam.

Daily mean flows ranged from 40 to 6130 cfs, with the mean being 497 cfs. These flows are 125% of historical (1938-2006) (see Fig. 34). Flows at this station are affected by regulation by Tongue River Dam operations and the operation of the TY diversion dam.

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 412 to 1100 µS/cm. Analytical SC values at this site ranged from 342 to 1140 µS/cm. Daily mean estimated SAR at this station ranged from 0.8 to 2.5. Analytical SAR values at this site ranged from 0.8 to 2.5. Mean Monthly SC values ranged from 452 to 915 µS/cm. Mean Monthly SAR values ranged from 0.9 to 2.1. All SC and SAR values measured or estimated were below the applicable MDEQ Standards for this site (see Fig. 35).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 36-38).

Tributary Sites

Goose Creek near Acme, WY

Table 9: Summary of USGS Monitoring Data
Goose Creek near Acme (station 06305700)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	16	41
		Max	1940	90
	SC (uS/cm)	Min	152	---
		Max	890	---
	Estimated SAR	Min	0.2	---
		Max	0.8	---
Analytical Values	SC (uS/cm)	Min	173	619
		Max	812	695
	SAR	Min	0.3	0.6
		Max	0.7	0.8
Mean Monthly*	SC (uS/cm)	Min	232	---
		Max	783	---
	SAR	Min	0.3	---
		Max	0.7	---

* Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. The 1999 WYPDES permits allow for the direct discharge of approximately 0.3 cfs (135 gpm) of untreated CBNG water to Goose Creek from 11 discharge points upstream from this station. Irrigation diversions/return flows are also occurring upstream from this station.

Daily mean flows ranged from 16 to 1940 cfs, with the mean being 198 cfs. These flows are 131% of historical (1984-2006) (see Fig. 39).

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 152 to 890 μS/cm. Analytical SC values at this site ranged from 173 to 812 μS/cm. Daily mean estimated SAR at this station ranged from 0.2 to 0.8. Analytical SAR values at this site ranged from 0.3 to 0.8. Mean Monthly SC values ranged from 232 to 783 μS/cm. Mean Monthly SAR values ranged from 0.3 to 0.7 (see Fig. 40).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2006 data along with historical data (see Figs. 41-43).

Prairie Dog Creek near Acme, WY

Table 10: Summary of USGS Monitoring Data
Prairie Dog Creek near Acme (station 06306250)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	4.6	7
		Max	292	21
	SC (uS/cm)	Min	777	---
		Max	2360	---
	Estimated SAR	Min	0.6	---
		Max	2.5	---
Analytical Values	SC (uS/cm)	Min	800	1500
		Max	1720	1960
	SAR	Min	0.6	1.2
		Max	1.8	1.5
Mean Monthly*	SC (uS/cm)	Min	1031	---
		Max	1519	---
	SAR	Min	0.9	---
		Max	1.5	---

* Mean Monthly Values are calculated by taking the simple mean of all daily mean and analytical samples collected during each calendar month, provided that at least 9 values were available.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. The "Brinkerhoff" permits allow for the discharge of untreated water into impoundments within the Prairie Dog Creek watershed. A permit for the discharge of treated water into Prairie Dog Creek has also been approved by WDEQ; this permit allows for the discharge of treated CBNG water with dissolved sodium less than 50 mg/l and EC<1000 μS/cm (Zygmunt, pers. com., 2006). Irrigation diversions/return flows also occur upstream from this station.

Daily mean flows during Water Year 2007 ranged from 4.6 to 292 cfs, with the mean being 33 cfs. These flows are 93% of historical (1970-2006) (see Fig. 44).

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 292 to 2360 μS/cm. Analytical SC values at this site ranged from 800 to 1960 μS/cm. Daily mean estimated SAR at this station ranged from 0.6 to 2.5. Analytical SAR values at this site ranged from 0.6 to 1.8. Mean Monthly SC values ranged from 1031 to 1519 μS/cm (see Fig. 45).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 46-48).

Hanging Woman Creek near Birney, MT

Table 11: Summary of USGS Monitoring Data
Hanging Woman Creek near Birney (station 06307600)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	0.0	0.0
		Max	248	0.03
	SC (uS/cm)	Min	1060	---
		Max	3490	---
	Estimated SAR	Min	2.3	---
		Max	6.6	---
Analytical Values	SC (uS/cm)	Min	921	2580
		Max	3540	2580
	SAR	Min	2.5	3.2
		Max	7.2	3.2
Mean Monthly*	SC (uS/cm)	Min	2860	---
		Max	3450	---
	SAR	Min	5.5	---
		Max	6.5	---

* Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Shading indicates value is in excess of the applicable standard.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. Nance Petroleum Corporation has permits for the discharge of untreated CBNG water into impoundments within the Wyoming portion of the Hanging Woman Creek watershed. Irrigation diversions/return flows are also occurring upstream from this station.

Daily mean flows during Water Year 2006 ranged from 0 to 248 cfs, with the mean being 3.3 cfs. These flows are 105% of historical (1973-2006) (see Fig. 49).

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 1060 to 3490 µS/cm. Analytical SC values at this site ranged from 921 to 3540 µS/cm. Daily mean estimated SAR at this station ranged from 2.3 to 6.6. Analytical SAR values at this site ranged from 2.5 to 7.2. Mean Monthly SC values ranged from 2860 to 3450 µS/cm. Mean Monthly SAR values ranged from 5.5 to 6.5. All SC values recorded or analyzed were far in excess of the MDEQ's EC standard for tributaries (500 µS/cm). SAR values were often in excess of the MDEQ's SAR standards (see Fig. 50).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 51-53).

Otter Creek at Ashland, MT

Table 12: Summary of USGS Monitoring Data
Otter Creek near Ashland (station 06307740)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	0.7	0.2
		Max	212	2
	SC (uS/cm)	Min	580	---
		Max	3650	---
	Estimated SAR	Min	3.0	---
		Max	7.3	---
Analytical Values	SC (uS/cm)	Min	1730	2360
		Max	3520	3700
	SAR	Min	4.6	5.3
		Max	6.6	6.5
Mean Monthly*	SC (uS/cm)	Min	1880	---
		Max	3120	---
	SAR	Min	4.8	---
		Max	6.6	---

*Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Shading indicates value is in excess of the applicable standard.

Realtime flow and SC were measured by continuous monitors at this site; realtime SAR was estimated from the SC data. Water-quality samples were also collected periodically. No CBNG discharge is occurring upstream of this station. Irrigation diversions/return flows occur upstream from this station.

Daily mean flows ranged from 0.7 to 212 cfs, with the mean being 4.4 cfs. These flows are 103% of historical (1972-2006) (see Fig. 54).

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 580 to 3650 µS/cm. Analytical SC values at this site ranged from 1730 to 3700 µS/cm. Daily mean estimated SAR at this station ranged from 3.0 to 7.3. Analytical SAR values at this site ranged from 4.6 to 6.6. Mean Monthly SC values ranged from 1880 to 3120 µS/cm. Mean Monthly estimated SAR values ranged from 4.8 to 6.6. All SC values recorded or analyzed were in excess of the MDEQ's EC standard for tributaries (500 µS/cm). Most of the recorded SAR values were in excess of the MDEQ's SAR standards (see Fig. 55).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 56-58).

Pumpkin Creek near Miles City, MT

Table 13: Summary of USGS Monitoring Data
Pumpkin Creek near Miles City (station 06308400)
Water Year 2007

			Irrigation Season	Non-Irrigation Season
Daily Means	Flow (cfs)	Min	0.0	0.0
		Max	705	426
	SC (uS/cm)	Min	407	---
		Max	4610	---
	Estimated SAR	Min	---	---
		Max	---	---
Analytical Values	SC (uS/cm)	Min	318	263
		Max	4430	263
	SAR	Min	3.0	2.6
		Max	10.4	2.6
Mean Monthly*	SC (uS/cm)	Min	959	---
		Max	4270	---
	SAR	Min	---	---
		Max	---	---

*Mean Monthly Values are calculated by taking the simple mean of all daily means and analytical results for samples collected during each calendar month, provided that at least 9 values were available.

Shading indicates value is in excess of the applicable standard.

Realtime flow and SC were measured by continuous monitors at this site. Realtime SAR was not estimated due to a poor regression relation with SC. Water-quality samples were also collected periodically. CBNG discharge is not occurring upstream of this station. Irrigation diversions/return flows are occurring upstream from this station.

Daily mean flows ranged from 0 to 705 cfs, with the mean being 20 cfs. These flows are 140% of historical (1972-2006) (see Fig. 59).

Daily mean SC data recorded during the seasonal period of operation at this station ranged from 407 to 4610 µS/cm. Analytical SC values at this site ranged from 263 to 4430 µS/cm. Analytical SAR values at this site ranged from 2.6 to 10.4. Daily mean SAR was not estimated at this station. Mean Monthly SC values ranged from 959 to 4270 µS/cm. There were not sufficient data available to calculate Mean Monthly SAR values. Most recorded SC values were in excess of the MDEQ's EC standard for tributaries (500 µS/cm). Most of the SAR analytical values were in excess of the MDEQ's SAR standards (see Fig. 60).

SC vs. Flow, SAR vs. Flow, and SC vs. SAR charts in the figures section present the 2007 data along with historical data (see Figs. 61-63).

Conclusions

During Water Year 2007 (October 1, 2006-September 30, 2007) flows within the Tongue River watershed were generally greater than historical; averaging 145% of historical for the mainstem stations. SC and SAR vary with flow conditions, so an evaluation of SC and SAR comparisons to historical values must also take flow into account.

The MDEQ and Northern Cheyenne surface water standards for EC and SAR in the main stem were not exceeded by values measured at stations on the Tongue River. The non-degradation criteria that would apply to new or increased discharges would be 40% of these standards. Historical values of SC and SAR would exceed the non-degradation criteria at all stations most of the time. Water Year 2007 values also exceed these criteria at all stations most of the time.

The MDEQ surface water standards for EC and SAR in tributaries were typically exceeded by values measured at stations near the mouth of tributaries. In some cases the existing conditions resulted in water quality values that were always in excess of the standards. These exceedances, even in watersheds where little or no CBNG development has occurred, indicate that non-CBNG factors are causing these high values. The non-degradation criteria would be 40% of the standards, resulting in nearly constant exceedance of these criteria.

At this time, the SC vs. Flow, SAR vs. Flow, and SAR vs. SC charts do not indicate a definitive difference between pre- and post-CBNG data, as 2007 values generally plot similar to historical values. This is in line with the conclusions of Clark and Mason (2007), who concluded that flow-adjusted SC values from 1991-2005 for the Tongue River at Monarch and the Tongue River at the State Line showed “No Trend”. Clark and Mason (2007) did not conduct a trend analysis for SAR at these sites since they either did not have sufficient data for water years 1991–2000, or data collection for SAR was interrupted, making the sites ineligible for the trend analysis. Some of the post-1999 and 2007 data for SC and SAR show signs of an upward shift in the charts for several sites, whereas other sites show no shift. Given the large scatter and inconsistent patterns of SC and SAR data among sites, some of the shifts may represent only temporary variations, possibly related to flow conditions. Future data may shed more light on the persistence of patterns that depart from historical ranges of values.

Acknowledgements:

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Figures

Figure 1: Comparison of Crop Yield to SC (Salinity) and Recorded 2007 SC Values in the Tongue River Watershed

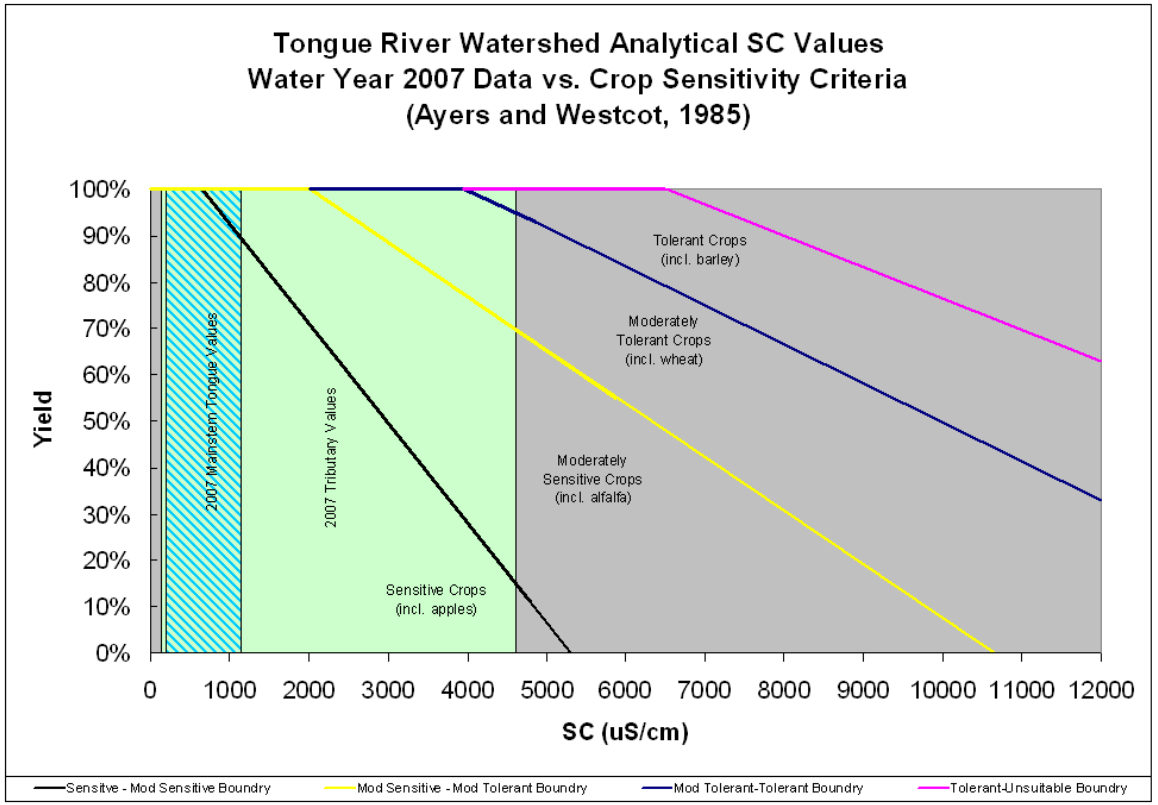


Figure 1 shows the range of SC values measured during water year 2007 compared to yield vs. salinity curves for representative crops. Note that yield comparisons are made to that which would be attained using low salinity irrigation water, and assumes that all other factors are equal. Mainstem values ranged from 169 to 1140 uS/cm. The high end of these values would be expected to cause approximately a 10% drop in the yield of sensitive crops (e.g. apples). Tributary values ranged from 152 to 4610 uS/cm. The high end of these values would be expected to cause approximately a 5% drop in the yield of moderately tolerant crops (e.g. wheat) a 30% drop in the yield of moderately sensitive crops (e.g. alfalfa), and approximately an 85% drop in the yield of sensitive crops (e.g. apples). CBNG water in the Montana portion of the PRB has a SC on the order of 2000 uS/cm. This salinity would have no impact on moderately sensitive crops (e.g. alfalfa) and would cause approximately a 30% drop in sensitive crop yields (e.g. apples).

Figure 2: Comparison of Stiff Plots for CBNG and Surface Waters

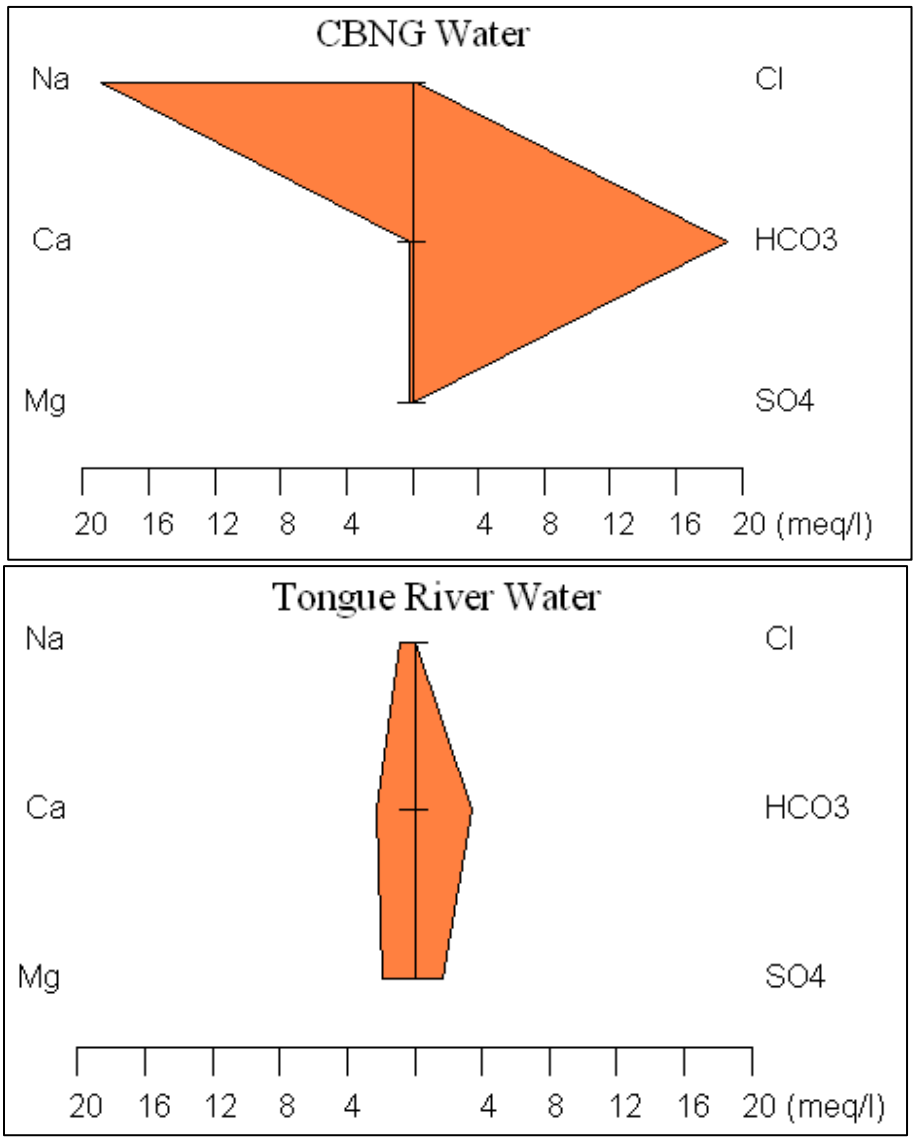


Figure 2 shows a comparison of the major ions in a representative sample of CBNG water from a well near Decker, MT, and from the Tongue River at the State Line USGS station. The CBNG water is dominated by Na and HCO_3 while the surface water sample is relatively balanced with Ca>Mg>Na and HCO_3>SO_4.

Figure 3: Comparison of Infiltration Criteria and Recorded 2007 SC and SAR Values in the Tongue River Watershed

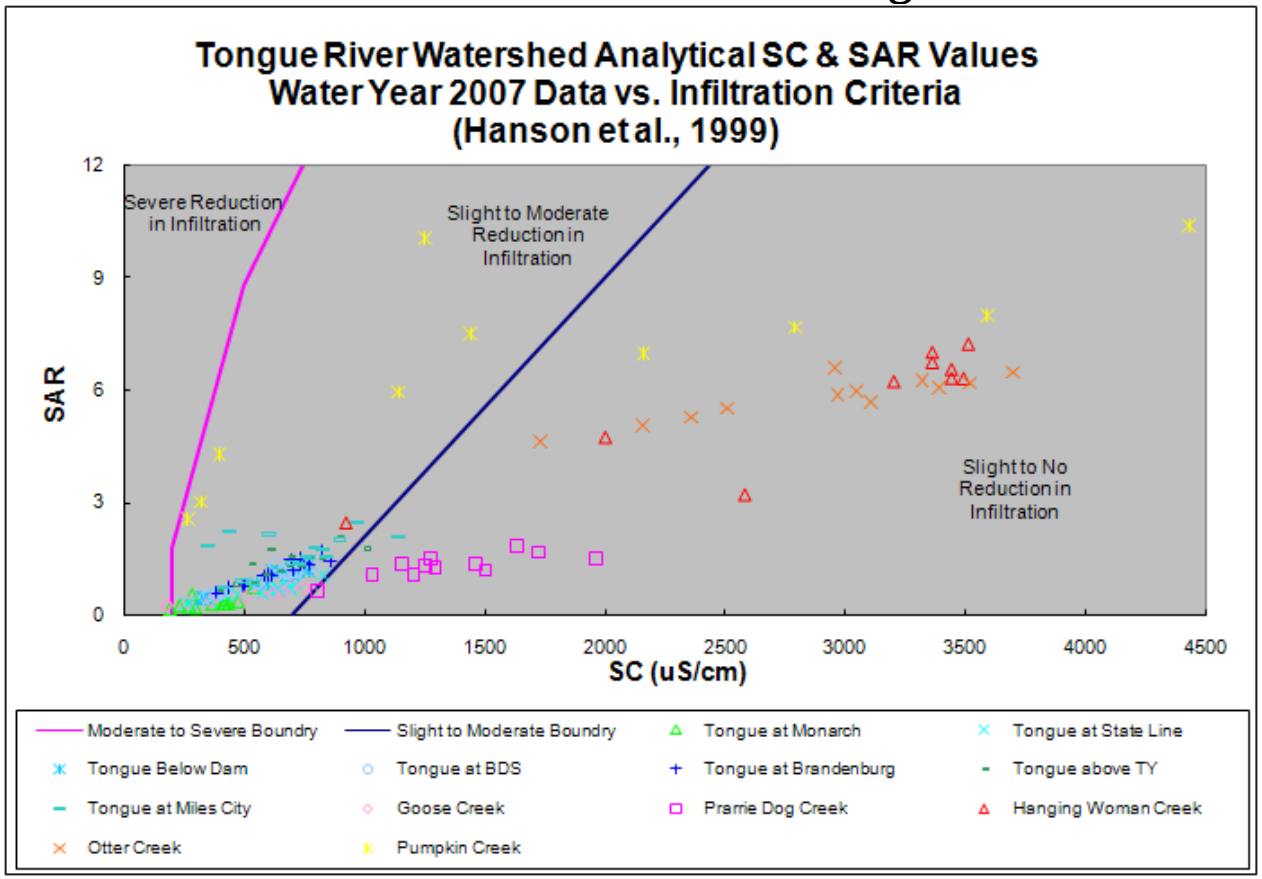


Figure 3 shows water quality data from water year 2007 in the Tongue River Watershed compared to the infiltration criteria developed by Hanson et al. (1999). Mainstem and Goose Creek values fall primarily within the "Slight to Moderate" reduction in infiltration field due to their relatively low SC values. Pumpkin Creek Values fall within the "Slight to Moderate" and the "Slight to No" reduction in infiltration fields due to its having relatively high SAR values compared to its SC. Other tributaries fall predominantly within the "Slight to No" reduction in infiltration field due to higher SC values relative to SAR.

Figure 4: Tongue River at Monarch, WY

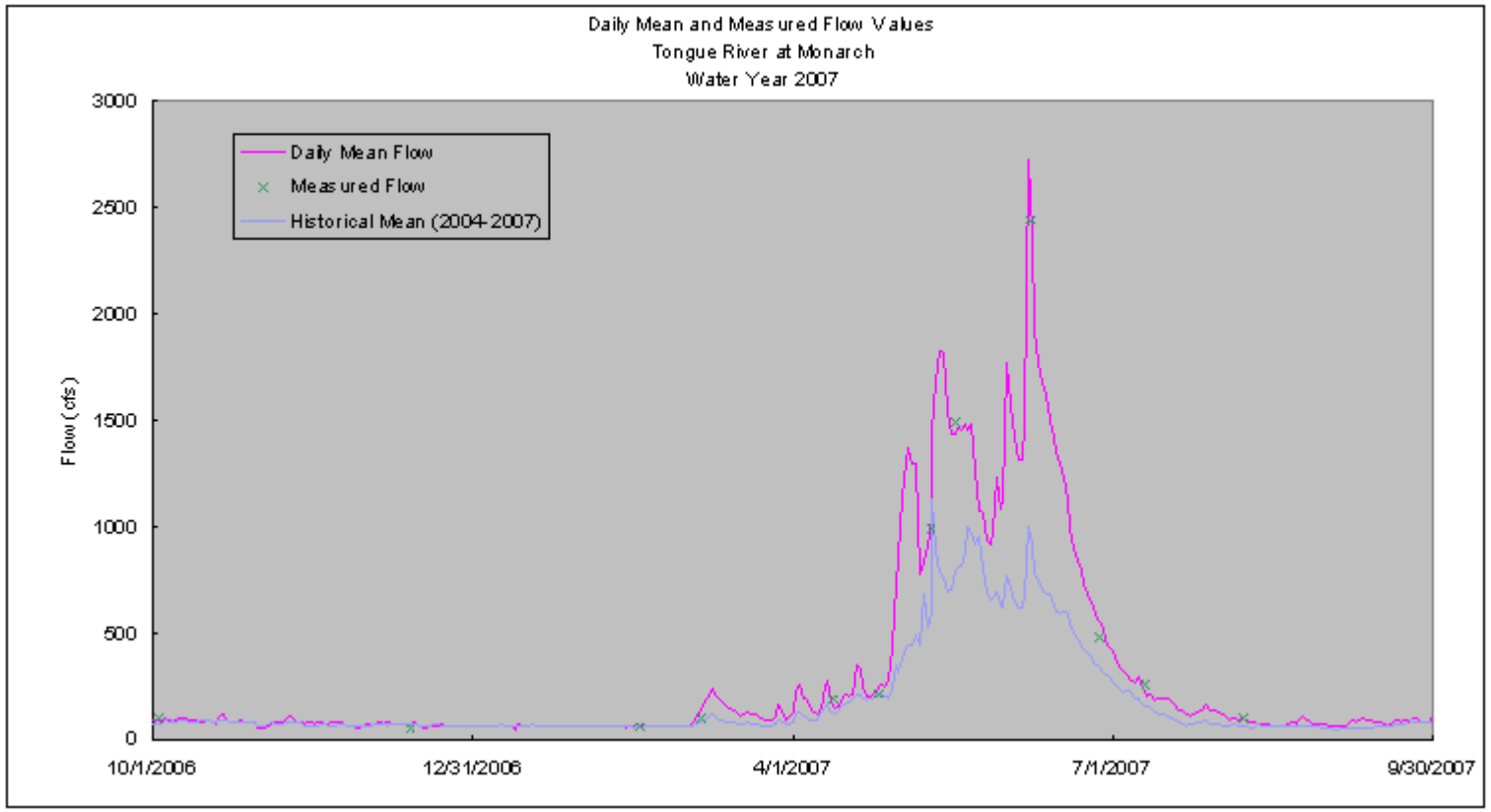
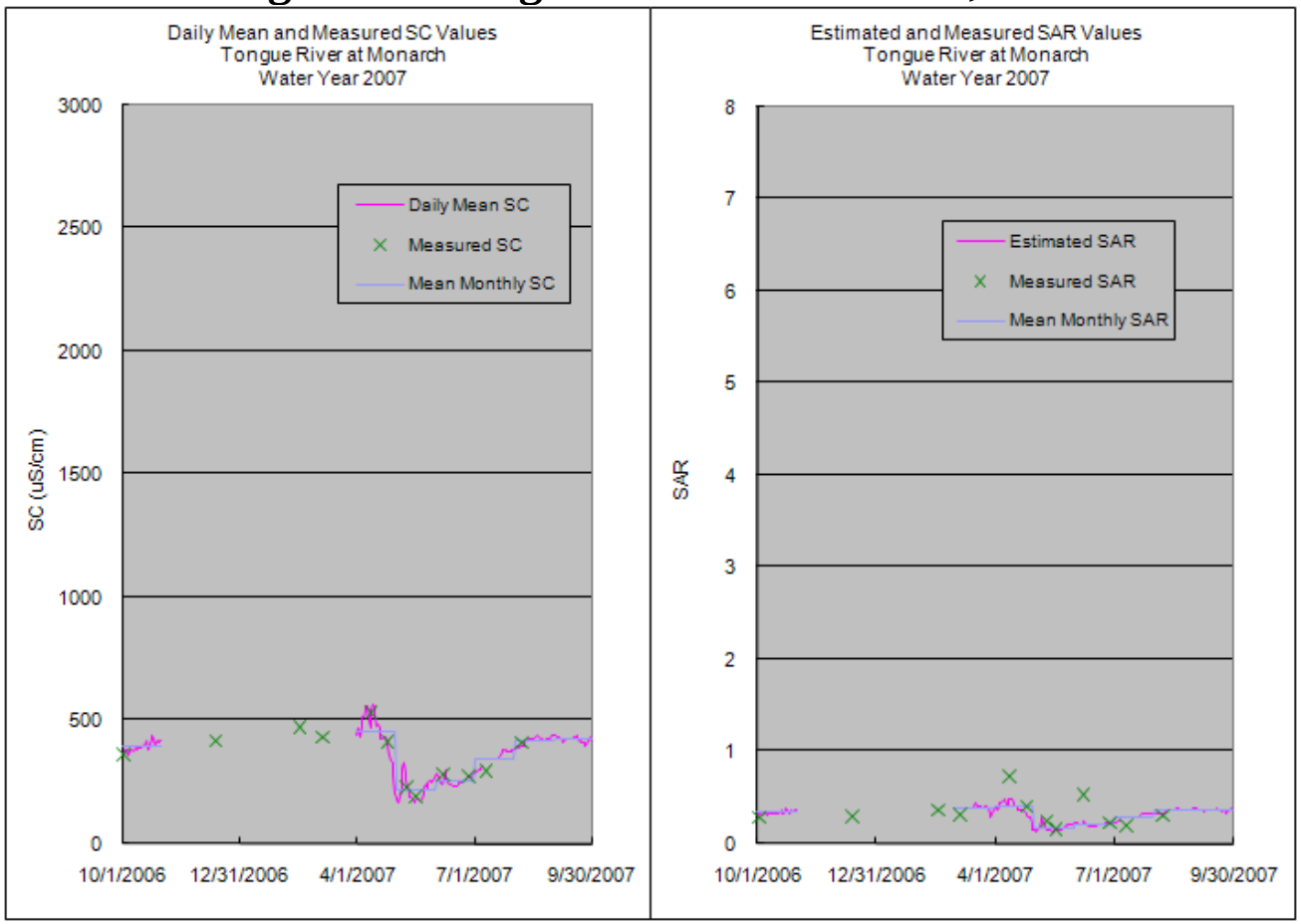


Figure 4 shows daily mean and field measurements of flow in a time series plot for water year 2007 for the Tongue River at Monarch. Daily mean flow values in water year 2007 ranged from 47 to 2720 cfs. Historical daily mean flow values are also shown. Cumulative 2007 flows were 168% of historical, which represents only a 4-year period.

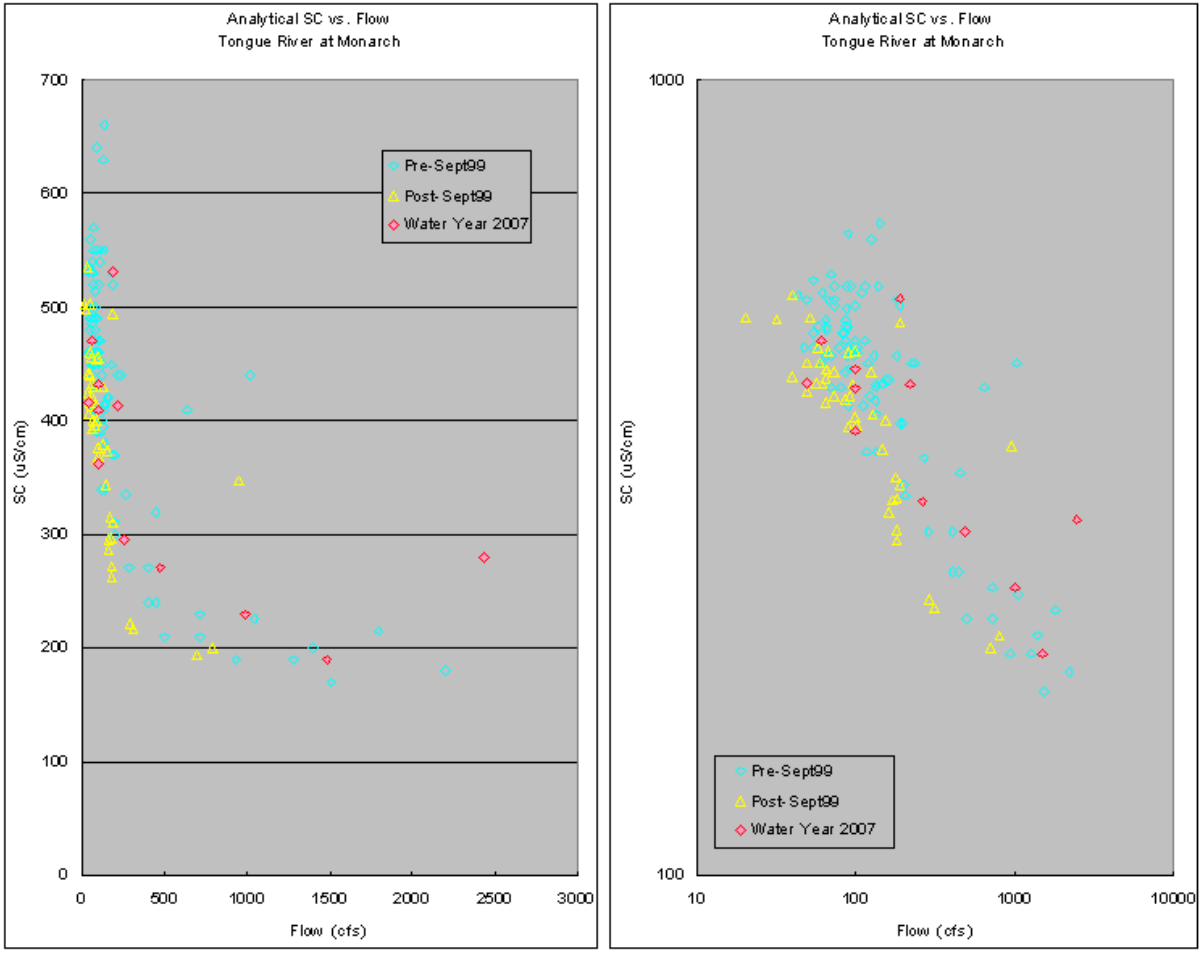
Figure 5: Tongue River at Monarch, WY



A **B**

Figure 5 shows analytical and daily mean SC values (A) and analytical and estimated SAR values (B) in time series plots for water year 2007 for the Tongue River at Monarch. Mean Monthly SC and SAR values are also shown. SC values ranged from 169 uS/cm to 565 uS/cm. Analytical SAR values ranged from 0.1 to 0.7.

Figure 6: Tongue River at Monarch, WY



A **B**

Figure 6 shows analytical SC vs. Flow data for water year 2007 for the Tongue River at Monarch. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 7: Tongue River at Monarch, WY

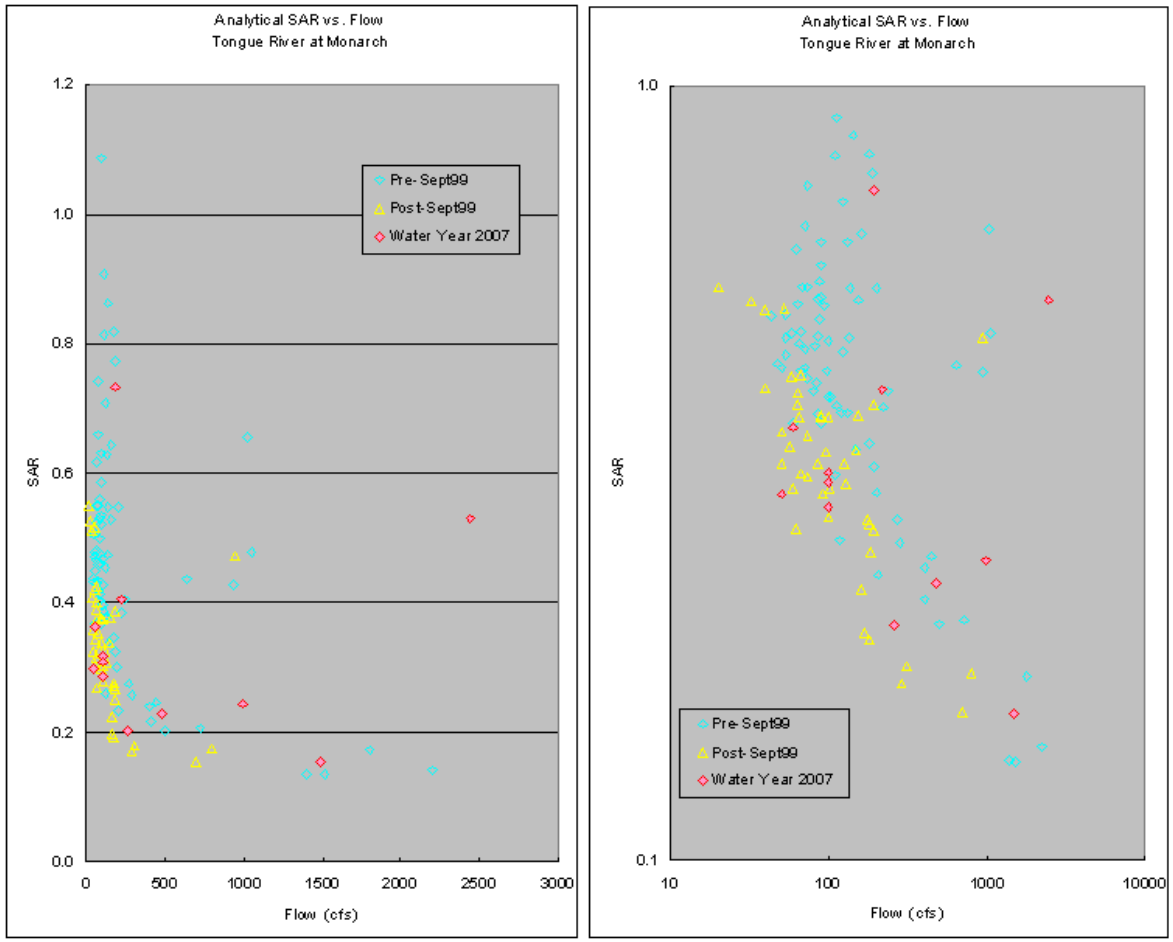


Figure 7 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River at Monarch. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 8: Tongue River at Monarch, WY

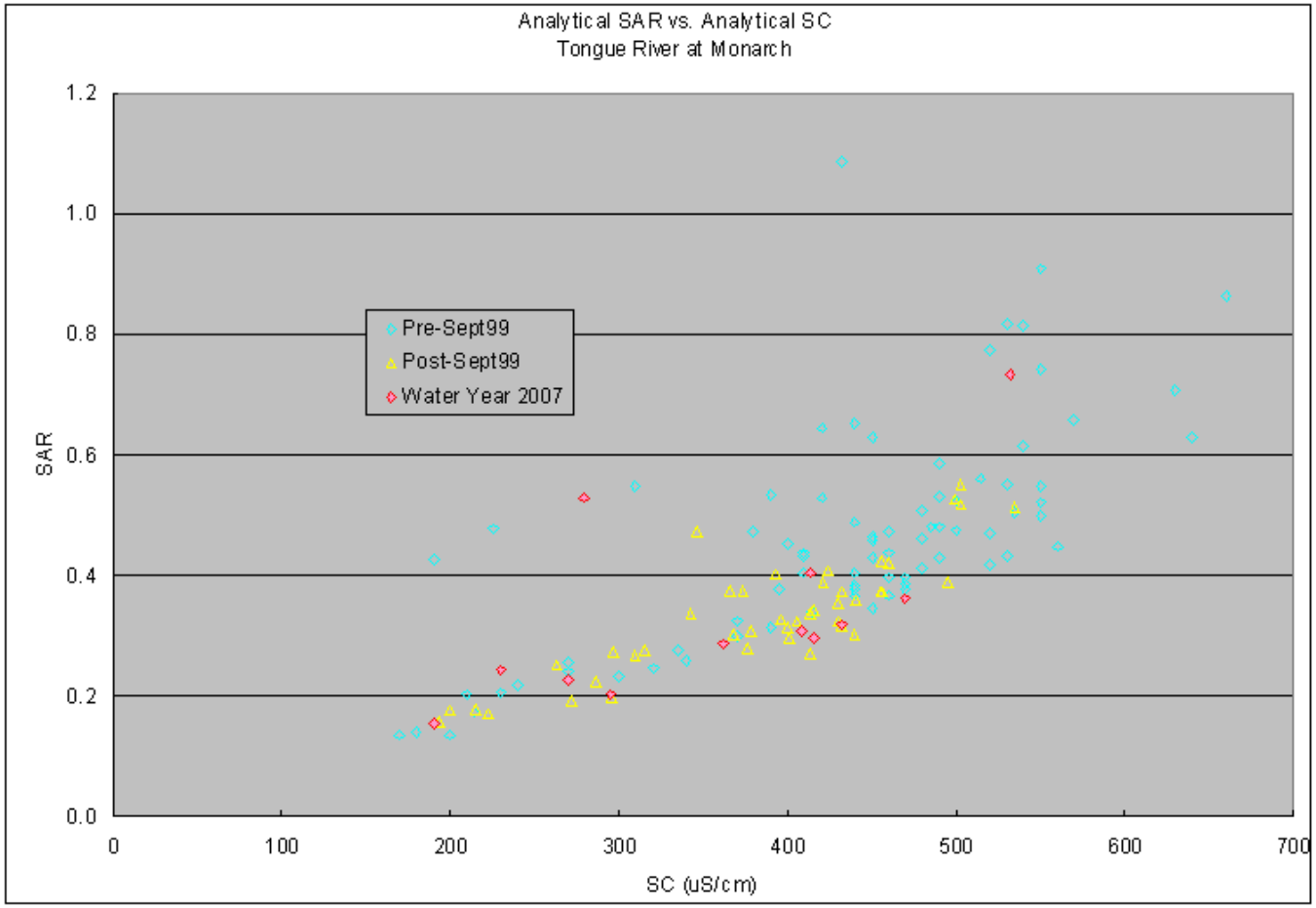


Figure 8 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River at Monarch. Historical SAR vs. SC data are also shown to place the data in context.

Figure 9: Tongue River at State Line, near Decker, MT

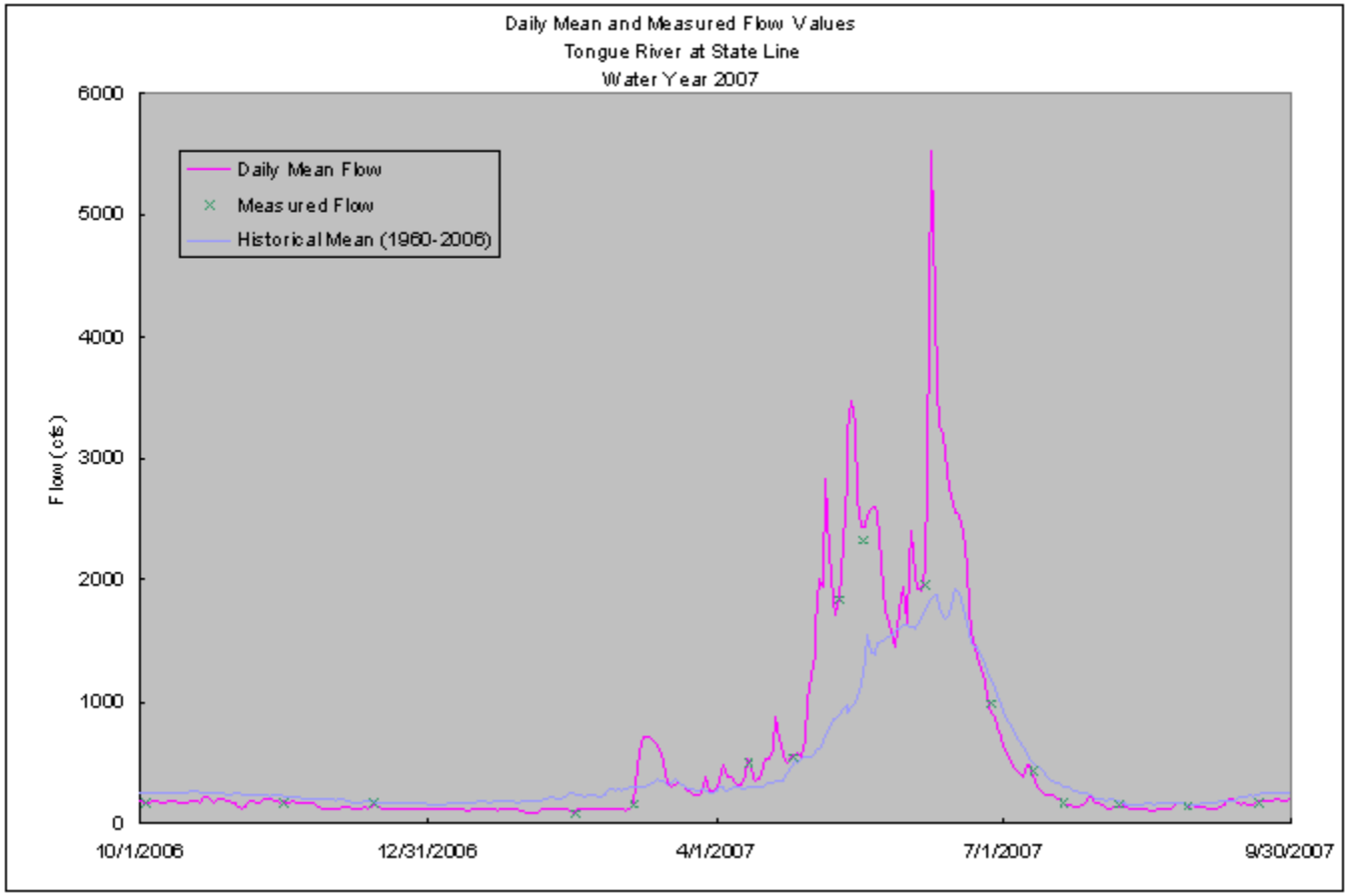
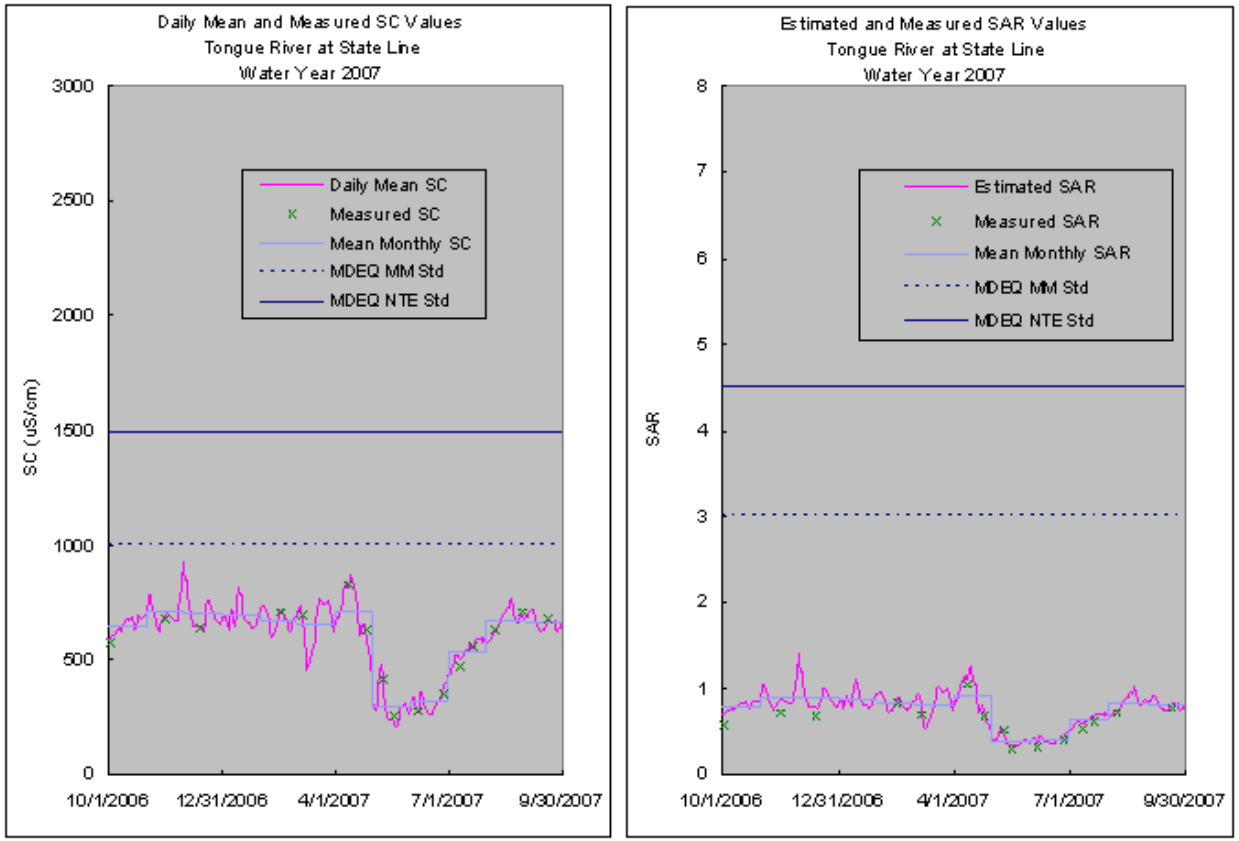


Figure 9 shows daily mean and field measurements of flow in a time series plot for water year 2007 for the Tongue River at the State Line. Daily Mean flow values during 2007 ranged from 70 to 5530 cfs. The historical average daily mean flow values are also shown. Cumulative 2007 flows were 125% of historical.

Figure 10: Tongue River at State Line, near Decker, MT



A **B**

Figure 10 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for the Tongue River at the State Line. Mean Monthly SC and SAR values are also shown. SC values ranged from 212 to 924 uS/cm. SAR values ranged from 0.3 to 1.4. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. Recorded values are below the applicable standards for the entire year. Note that the irrigation season standards apply year-round upstream of the reservoir.

Figure 11: Tongue River at State Line, near Decker, MT

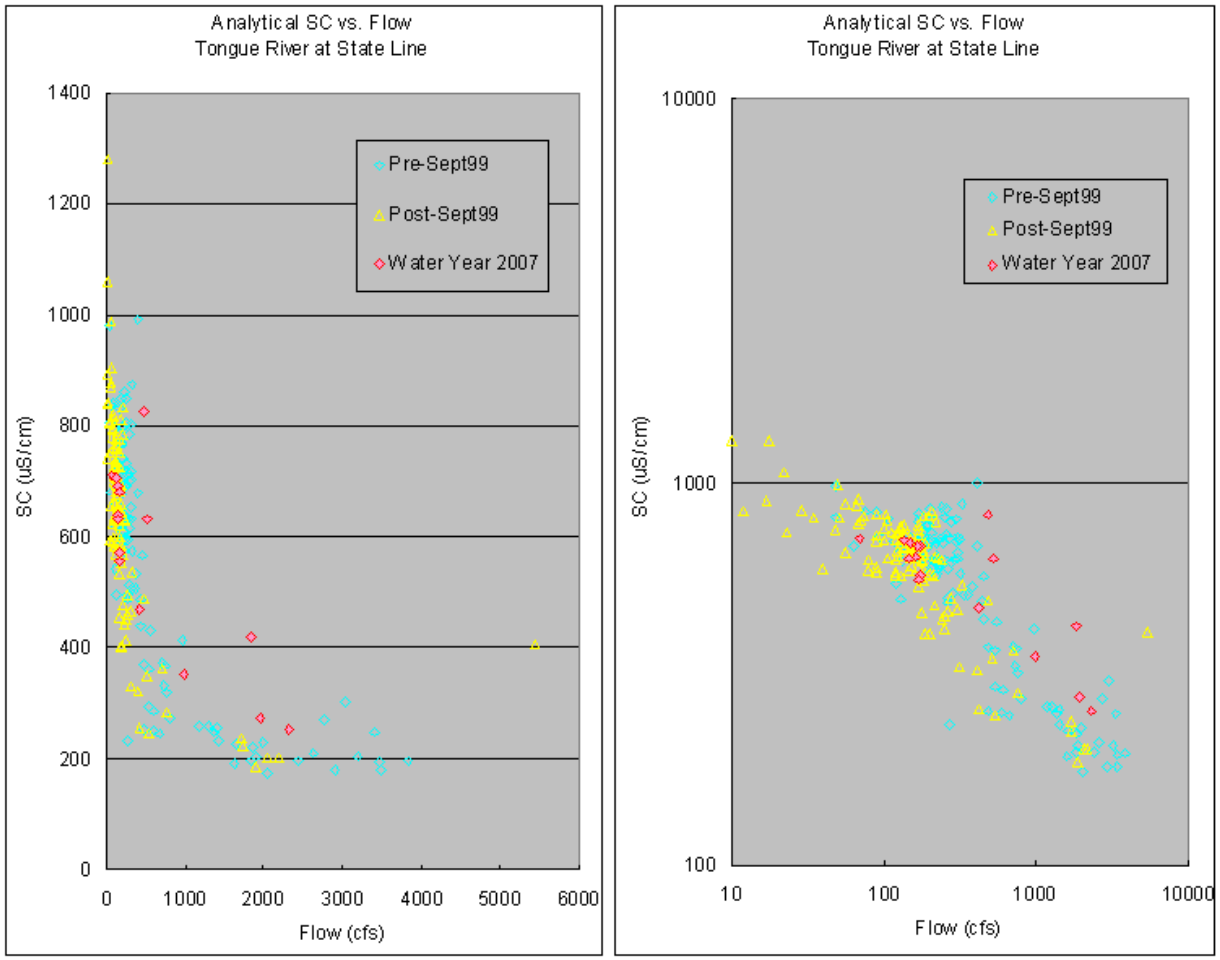
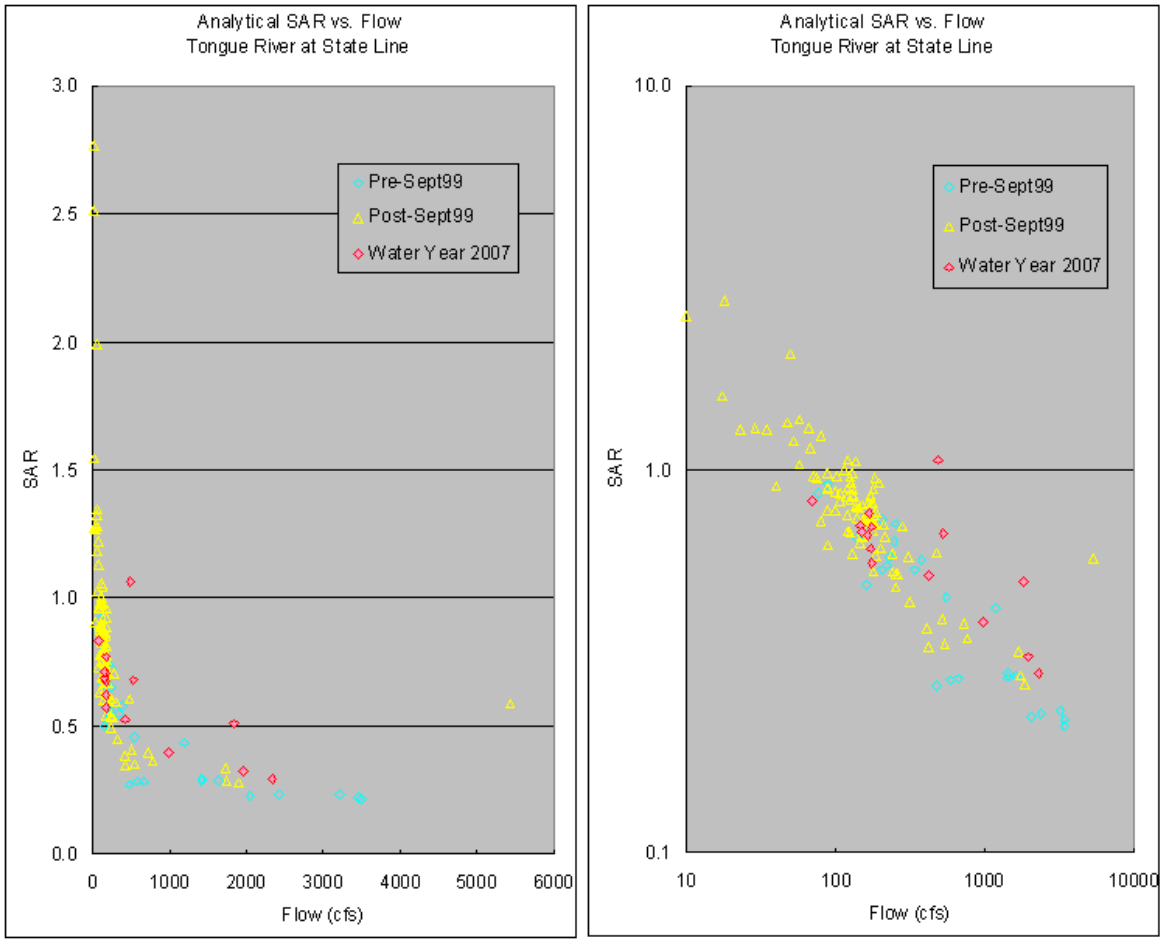


Figure 11 shows analytical SC vs. Flow data for water year 2007 for the Tongue River at the State Line. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 12: Tongue River at State Line, near Decker, MT



A **B**

Figure 12 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River at the State Line. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 13: Tongue River at State Line, near Decker, MT

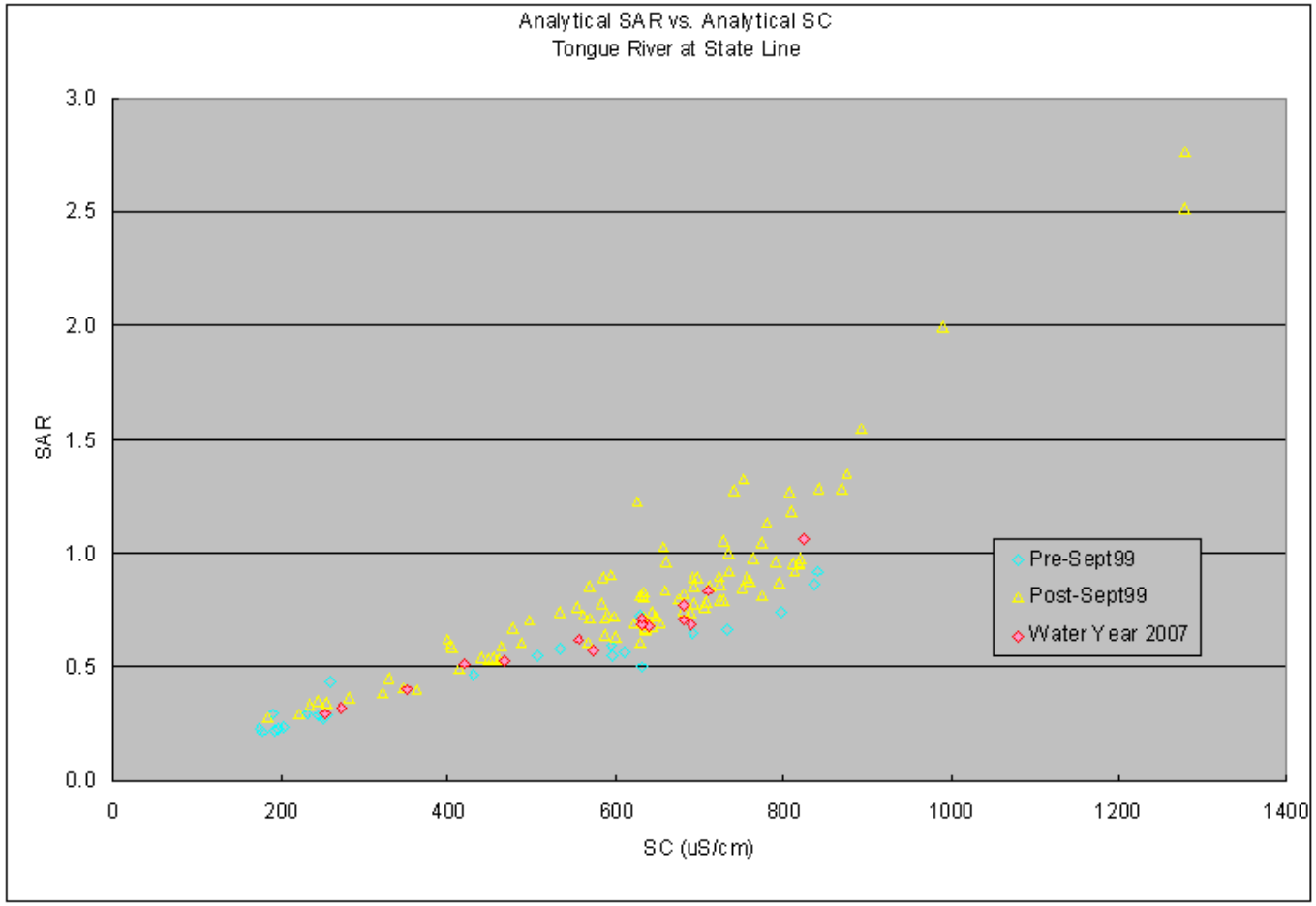


Figure 13 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River at the State Line. Historical SAR vs. SC data are also shown to place the data in context.

Figure 14: Tongue River at Tongue River Dam, near Decker, MT

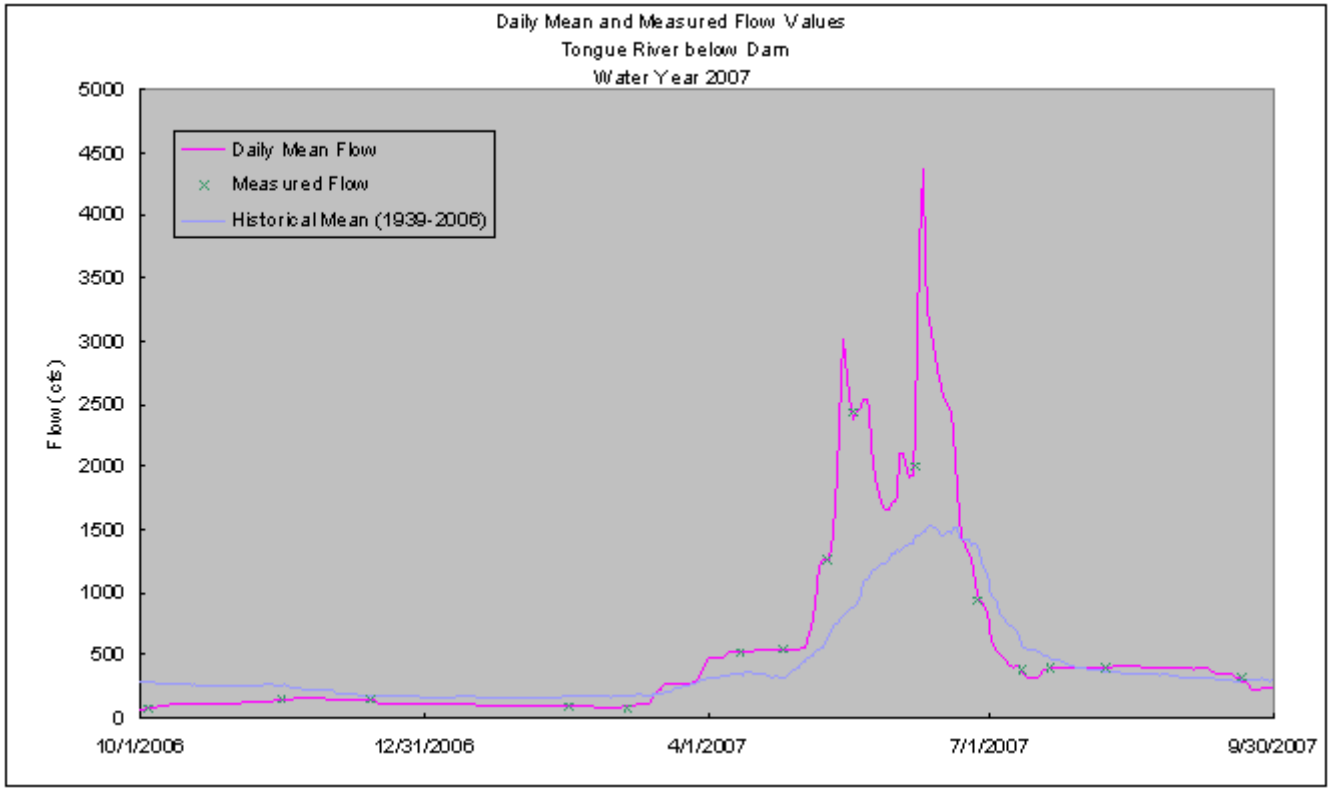
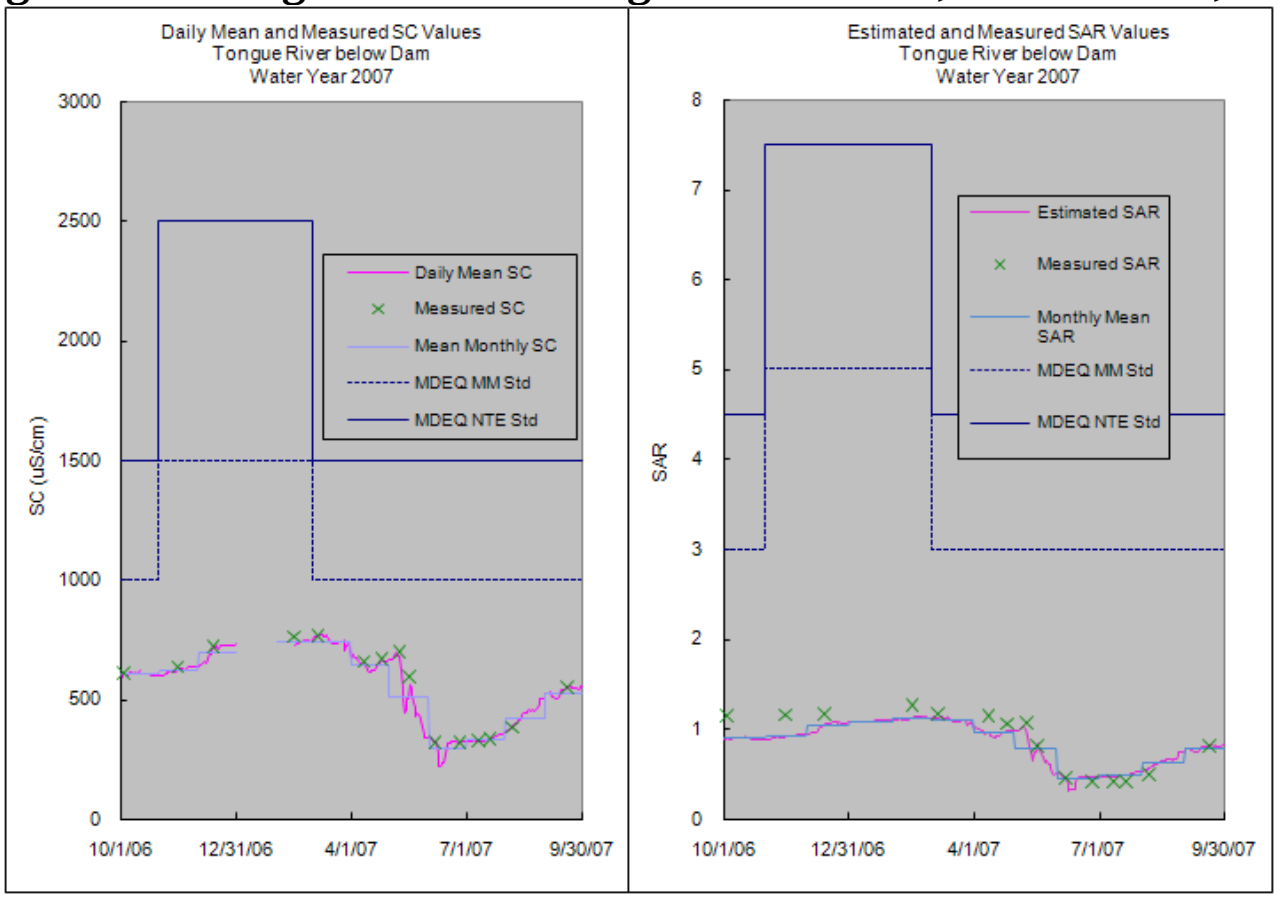


Figure 14 shows daily mean and field measurements of flow in a time series plot for water year 2007 for the Tongue River at Tongue River Dam, near Decker. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 58 to 4370 cfs. The historical average daily mean flow values are also shown. Cumulative 2007 flows were 123% of historical.

Figure 15: Tongue River at Tongue River Dam, near Decker, MT



A **B**

Figure 15 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for the Tongue River at Tongue River Dam, near Decker. Mean Monthly SC and SAR values are also shown. SC values ranged from 217 to 770 uS/cm. SAR values ranged from 0.3 to 1.3. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. Measured and estimated values are below the appropriate standards for the entire year.

Figure 16: Tongue River at Tongue River Dam, near Decker, MT

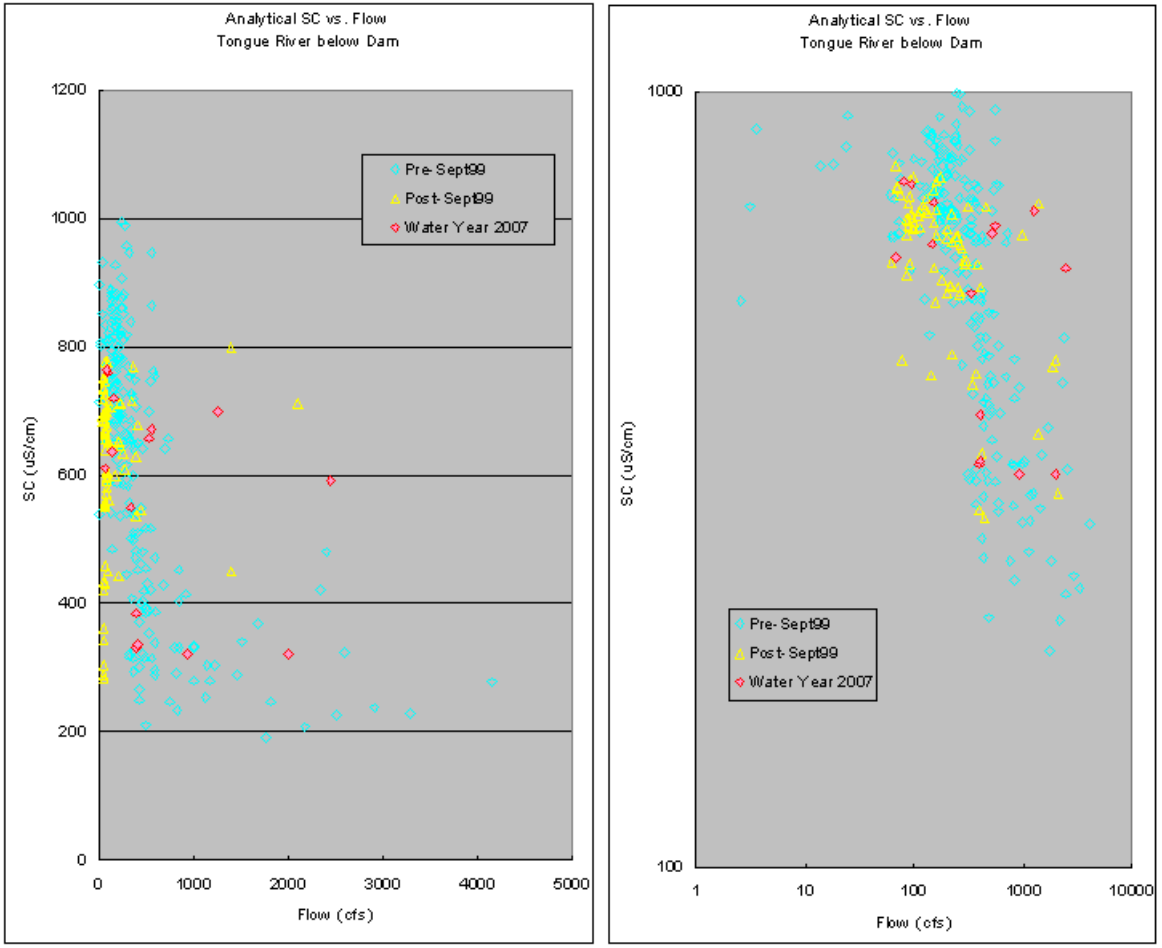
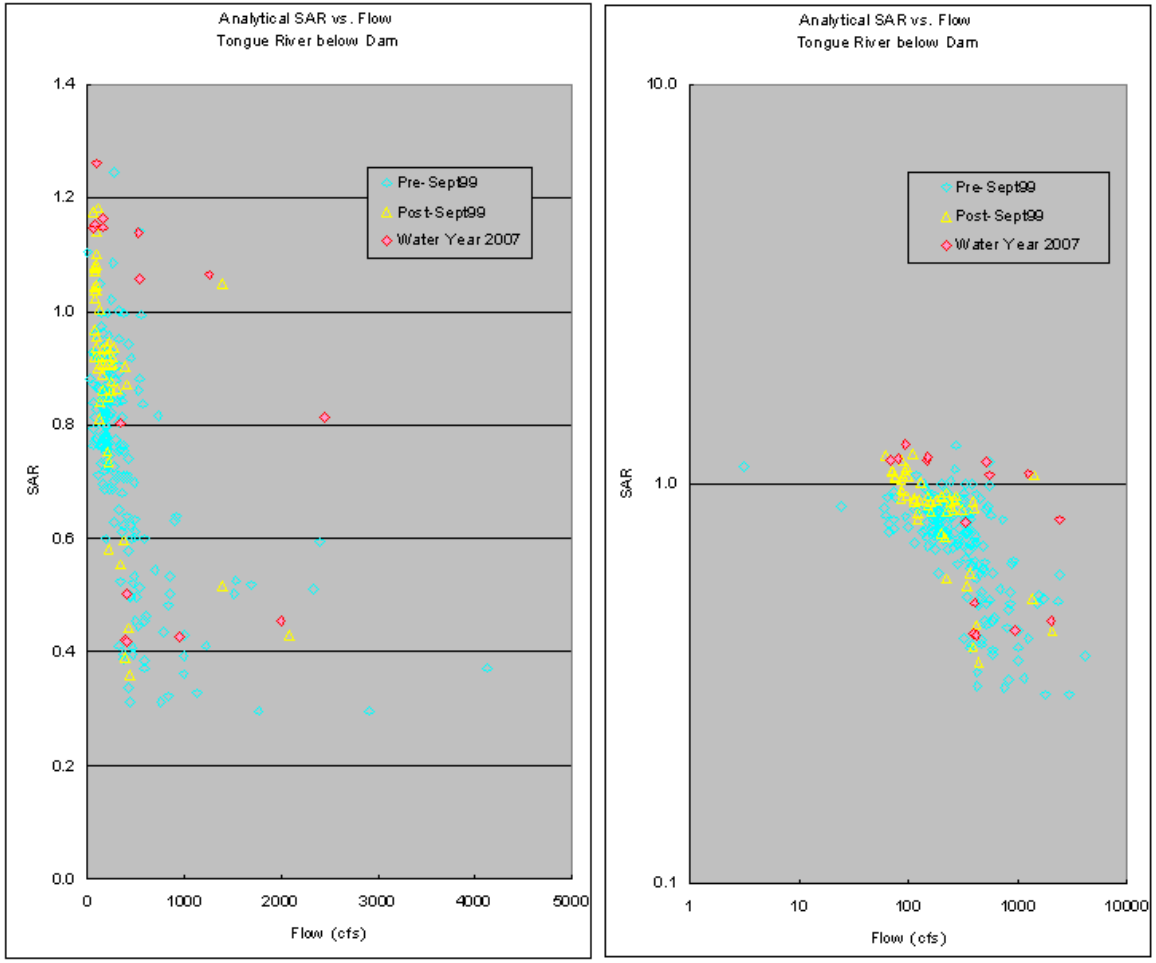


Figure 16 shows analytical SC vs. Flow data for water year 2007 for the Tongue River at Tongue River Dam, near Decker. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 17: Tongue River at Tongue River Dam, near Decker, MT



A **B**

Figure 17 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River at Tongue River Dam, near Decker. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 18: Tongue River at Tongue River Dam, near Decker, MT

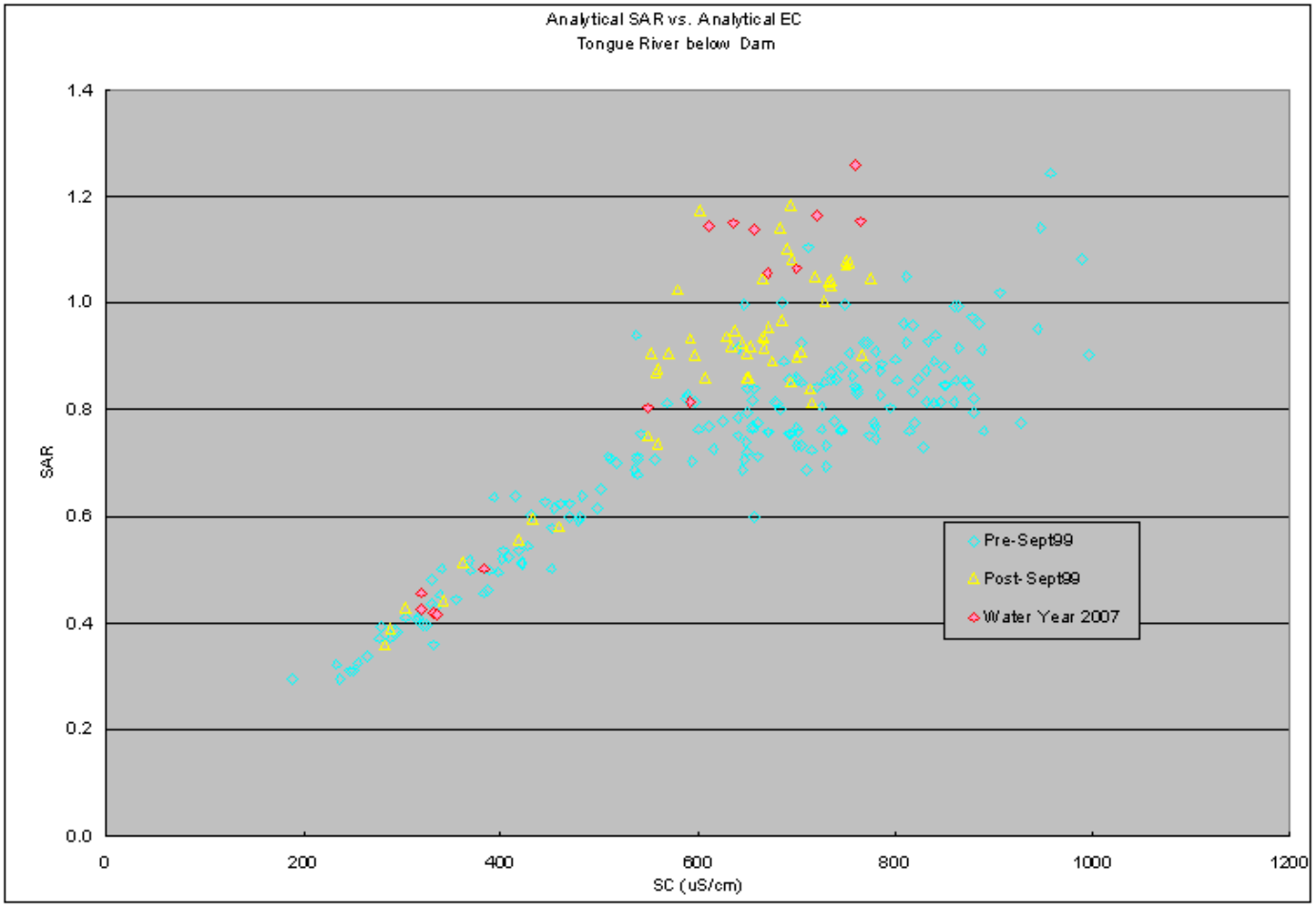


Figure 18 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River at Tongue River Dam, near Decker. Historical SAR vs. SC data are also shown to place the data in context.

Figure 19: Tongue River at Birney Day School Bridge, near Birney, MT

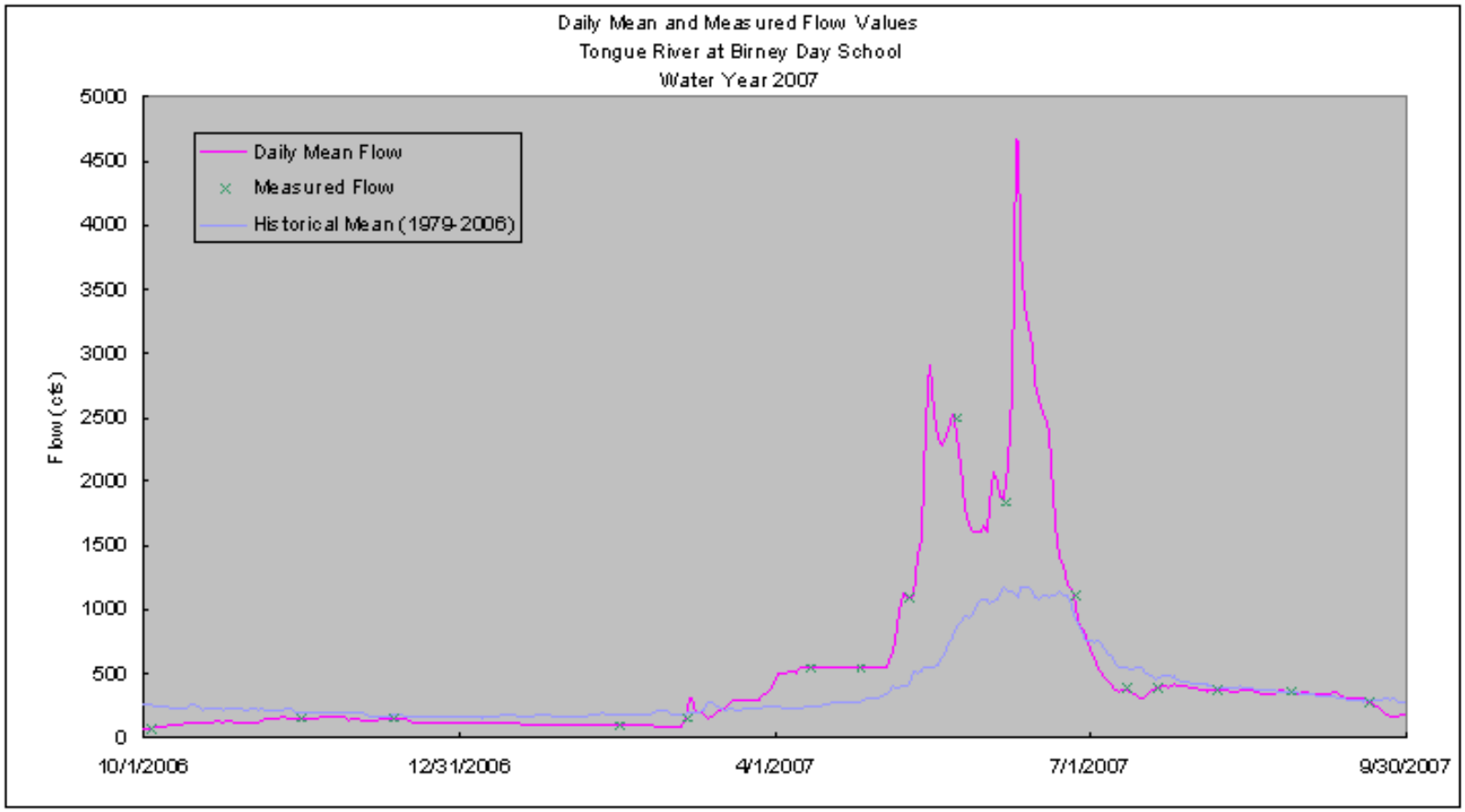
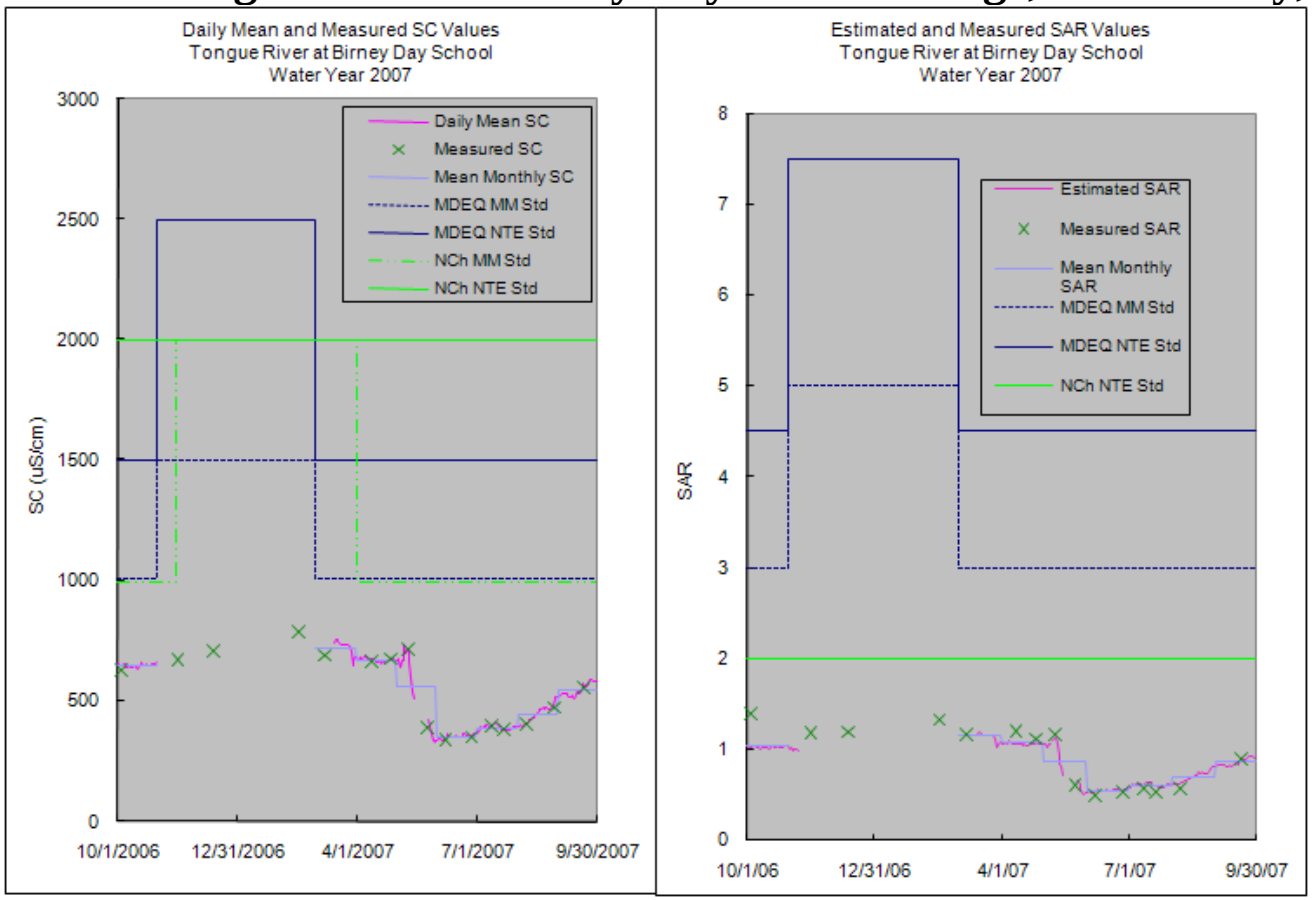


Figure 19 shows mean daily and field measurements of flow in a time series plot for water year 2007 for the Tongue River at Birney Day School Bridge, near Birney. The historical average mean daily flow values are also shown. Flow values ranged from 59 to 4670 cfs. Cumulative 2007 flows were 142% of historical. Flows are strongly influenced by reservoir operations.

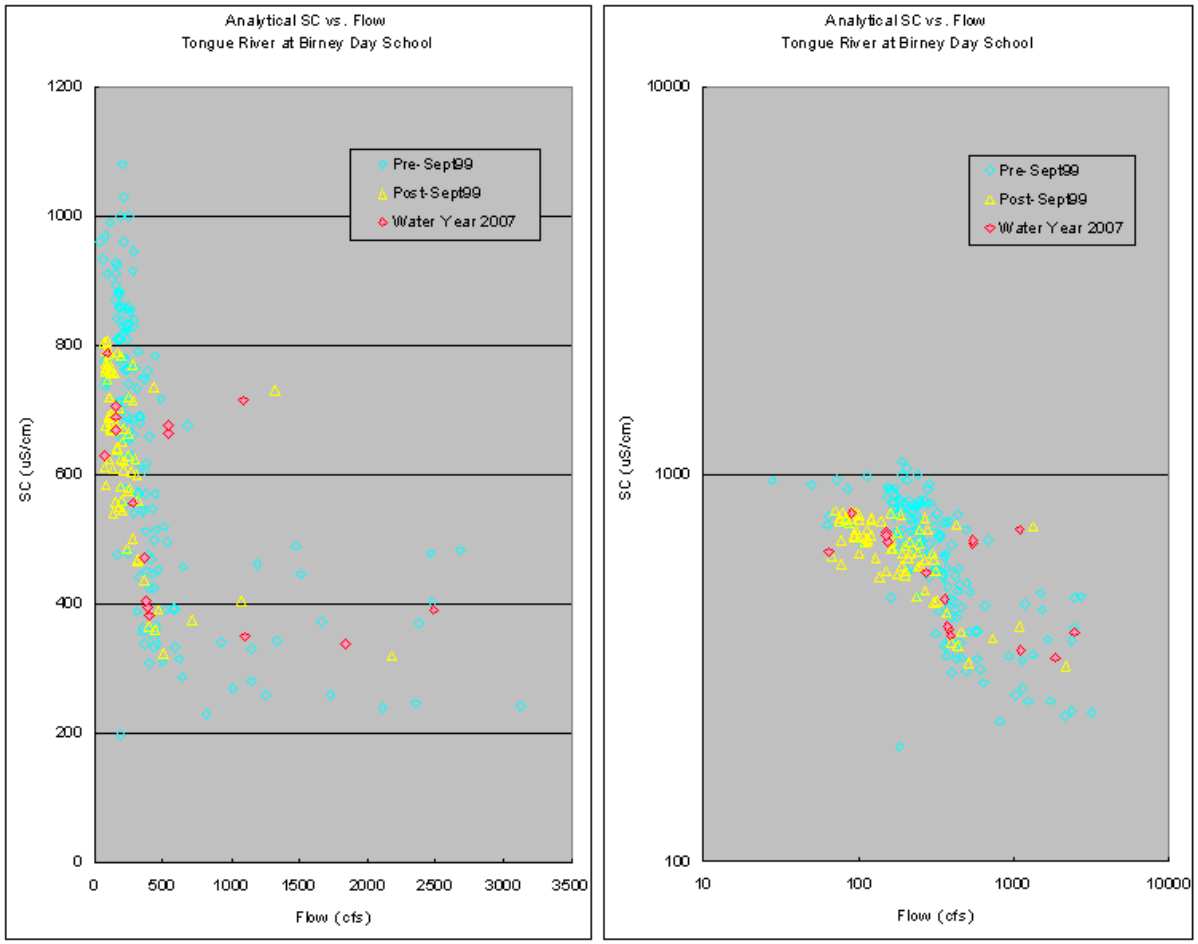
Figure 20: Tongue River at Birney Day School Bridge, near Birney, MT



A **B**

Figure 20 shows analytical and daily mean SC values (A) and analytical SAR values (B) values in time series plots for water year 2007 for the Tongue River at Birney Day School Bridge, near Birney. Mean Monthly SC values are also shown. SC values ranged from 327 to 789 uS/cm. Analytical SAR values ranged from 0.5 to 1.4. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ and the Northern Cheyenne Tribe. Measured and estimated values are below the applicable standards for the entire year.

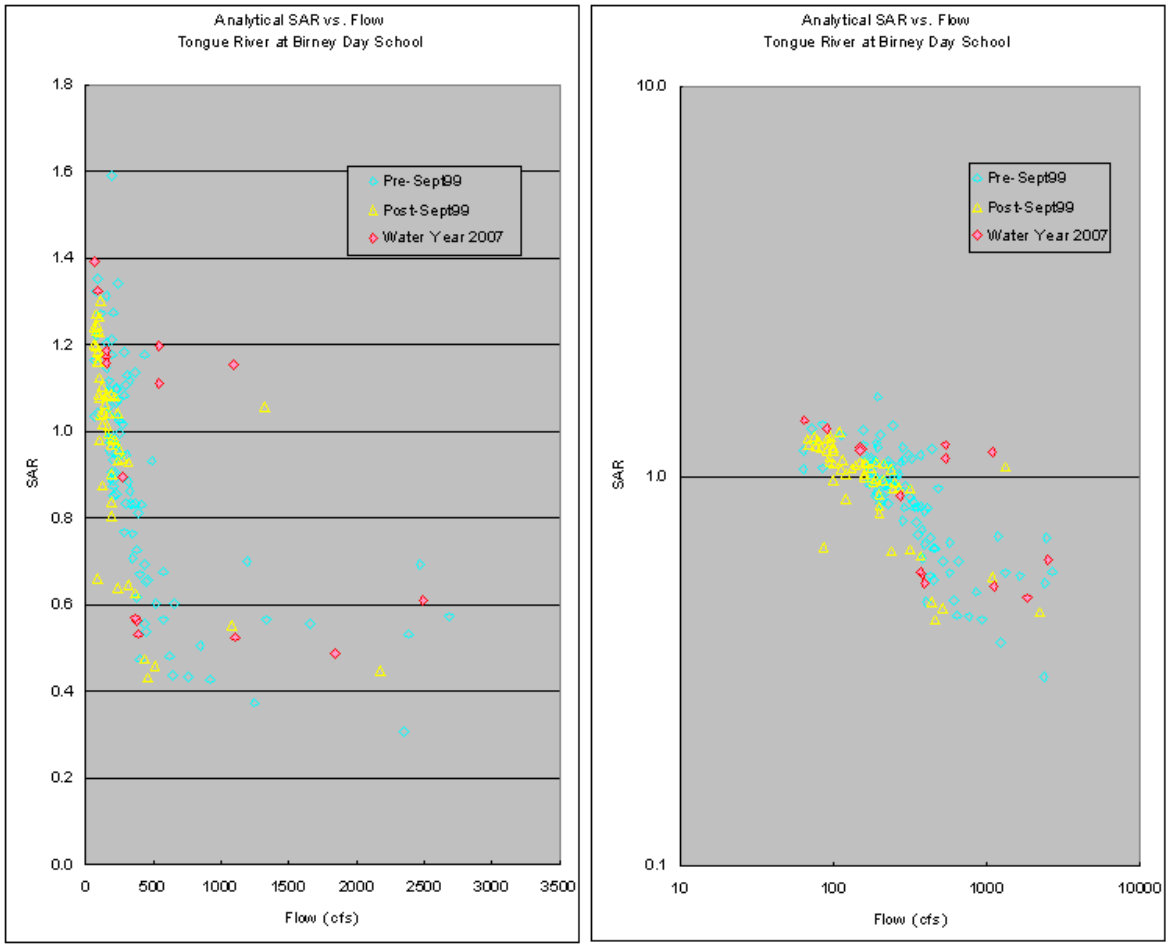
Figure 21: Tongue River at Birney Day School Bridge, near Birney, MT



A **B**

Figure 21 shows analytical SC vs. Flow data for water year 2007 for the Tongue River at Birney Day School Bridge, near Birney. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 22: Tongue River at Birney Day School Bridge, near Birney, MT



A **B**

Figure 22 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River at Birney Day School Bridge, near Birney, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 23: Tongue River at Birney Day School Bridge, near Birney, MT

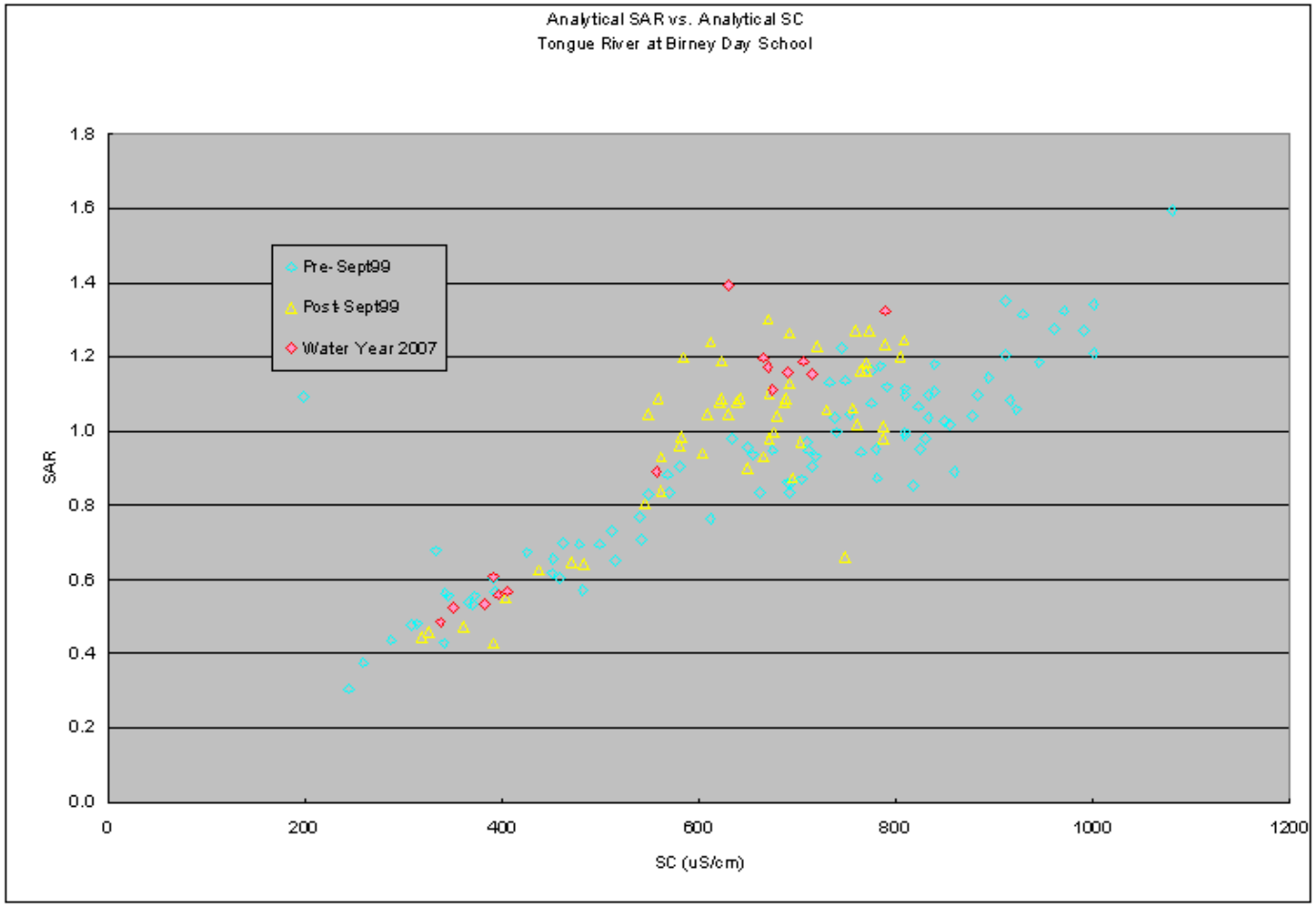


Figure 23 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River at Birney Day School. Historical SAR vs. SC data are also shown to place the data in context.

Figure 24: Tongue River below Brandenburg Bridge, near Ashland, MT

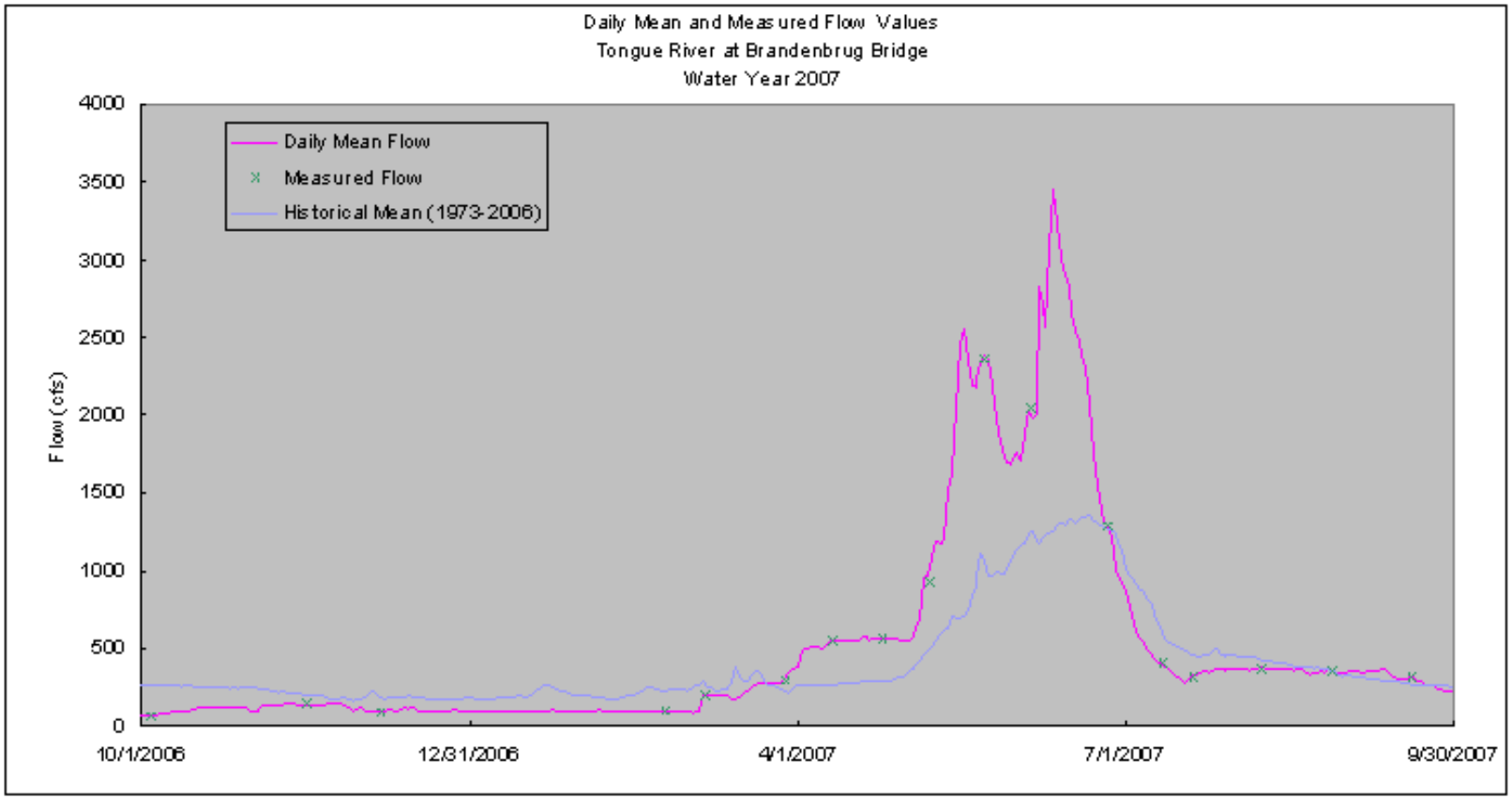
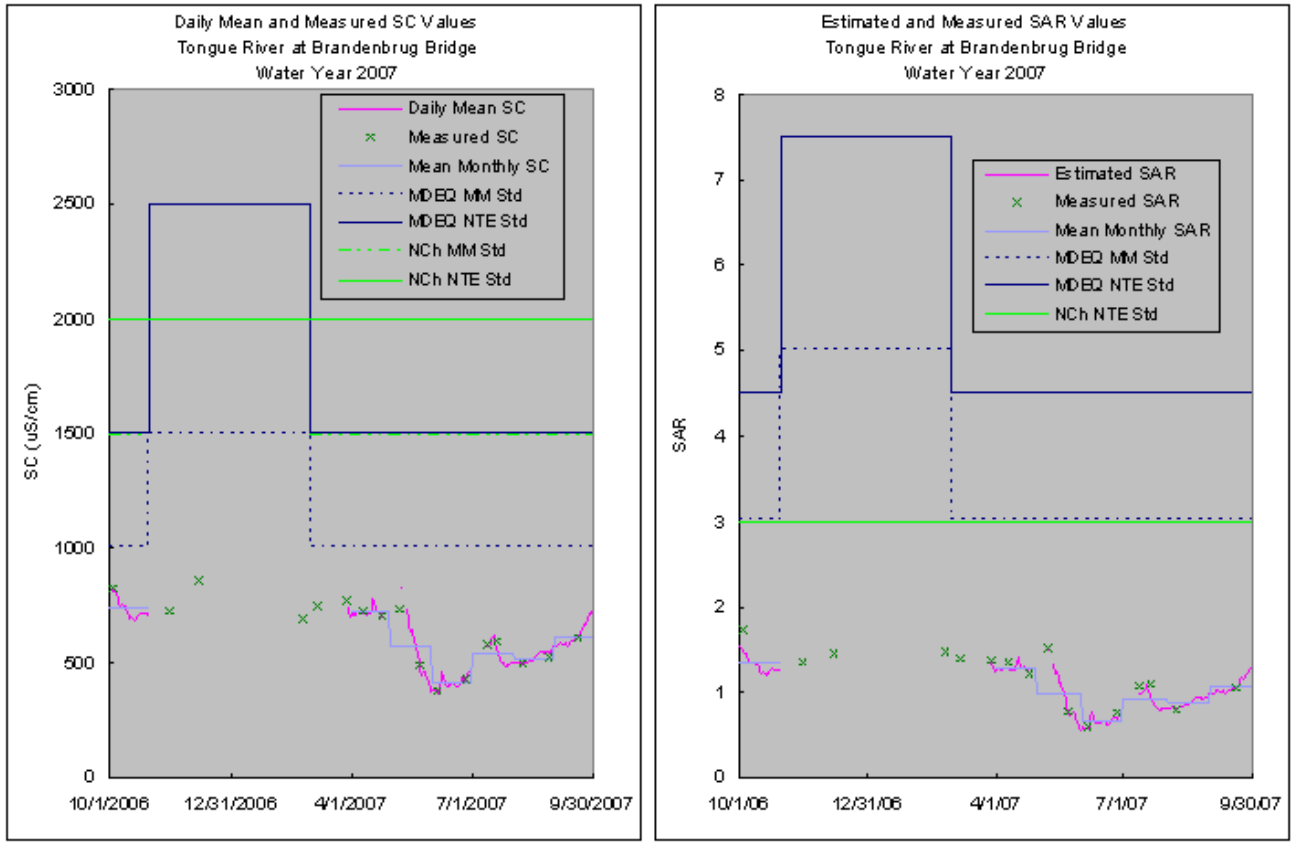


Figure 24 shows daily mean and field measurements of flow in a time series plot for water year 2007 for the Tongue River below Brandenburg Bridge. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 58 to 3460 cfs. Cumulative 2007 flows were 126% of historical.

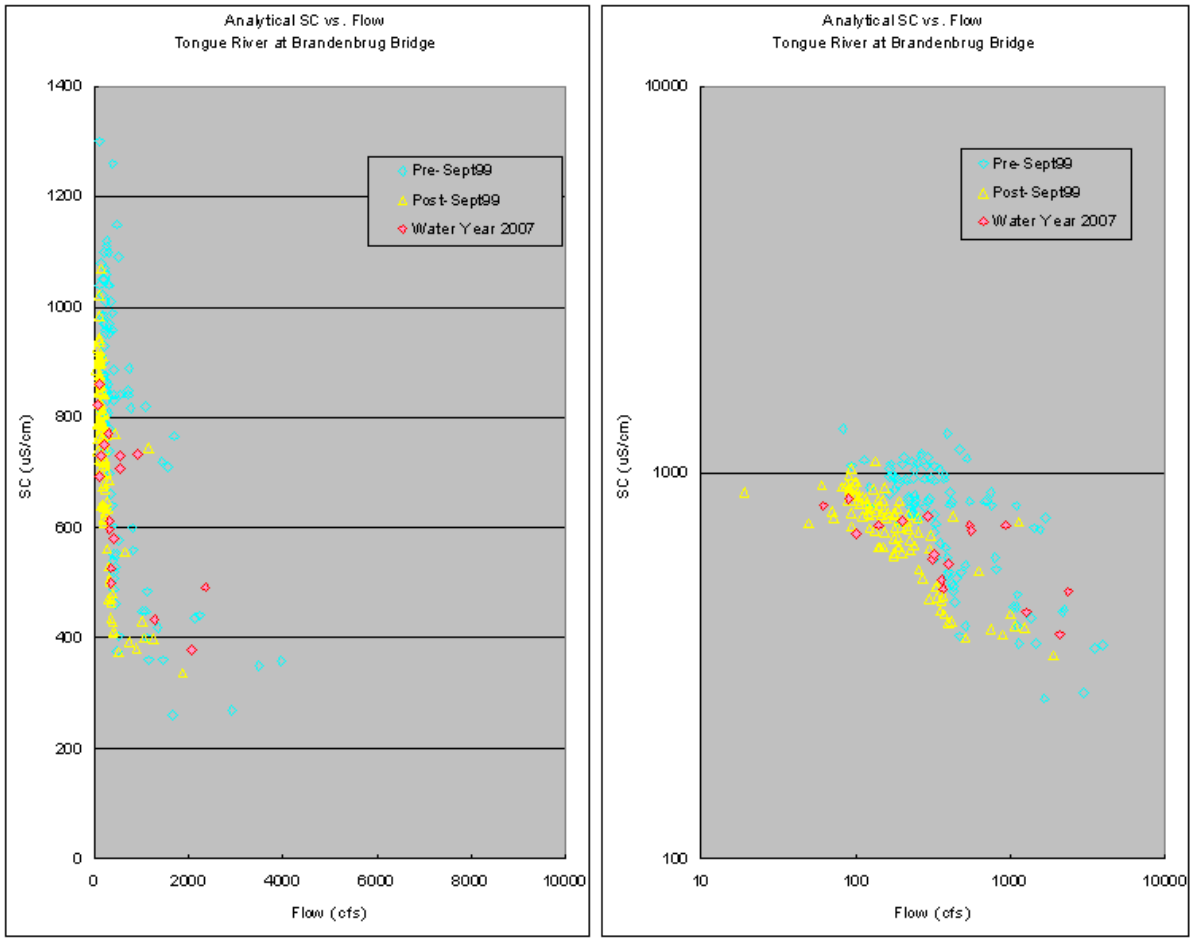
Figure 25: Tongue River below Brandenburg Bridge, near Ashland, MT



A **B**

Figure 25 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for the Tongue River below Brandenburg Bridge, near Ashland, MT. Mean Monthly SC and SAR values are also shown. SC values ranged from 362 to 841 uS/cm. SAR values ranged from 0.6 to 1.7. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ and the Northern Cheyenne Tribe. Measured and estimated values are below these standards for the entire year.

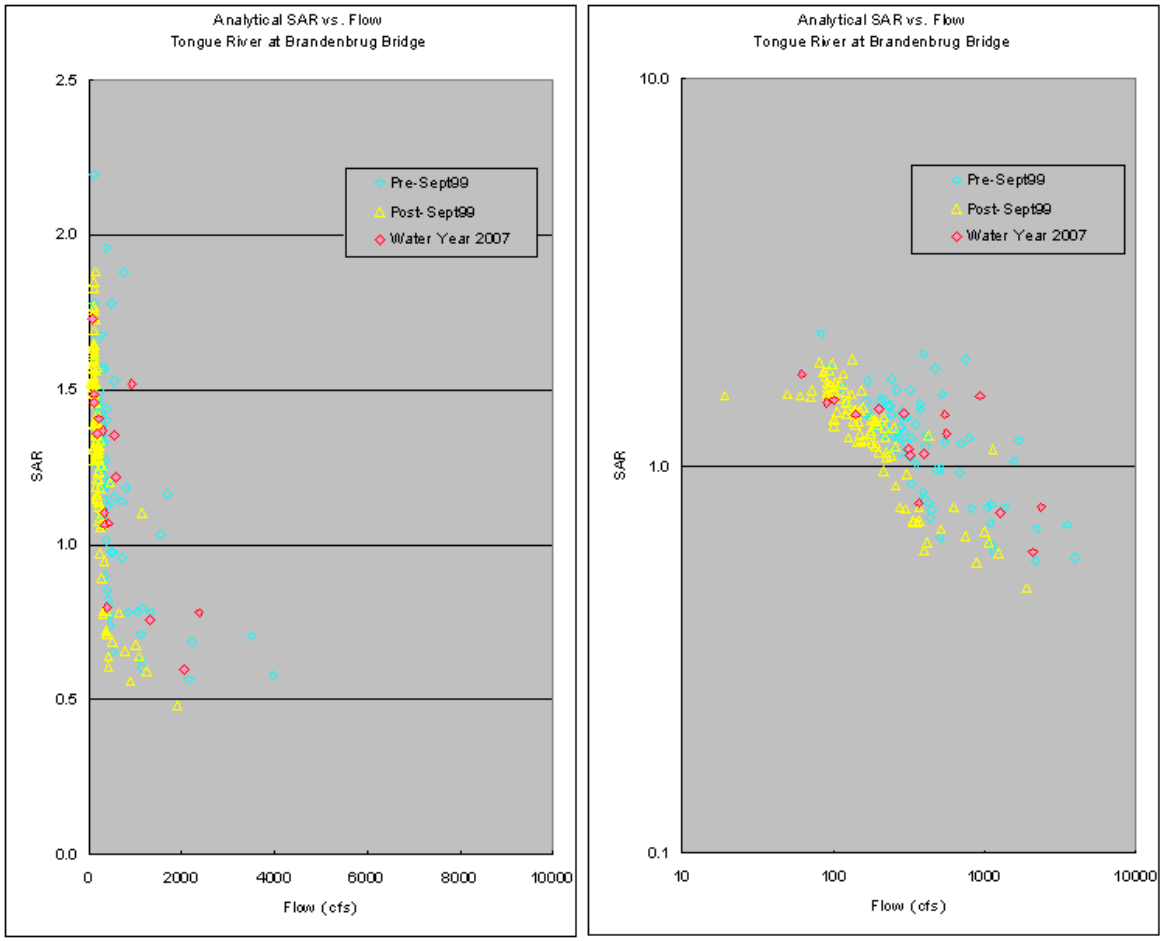
Figure 26: Tongue River below Brandenburg Bridge, near Ashland, MT



A **B**

Figure 26 shows analytical SC vs. Flow data for water year 2007 for the Tongue River below Brandenburg Bridge, near Ashland, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 27: Tongue River below Brandenburg Bridge, near Ashland, MT



A **B**

Figure 27 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River below Brandenburg Bridge, near Ashland, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 28: Tongue River below Brandenburg Bridge, near Ashland, MT

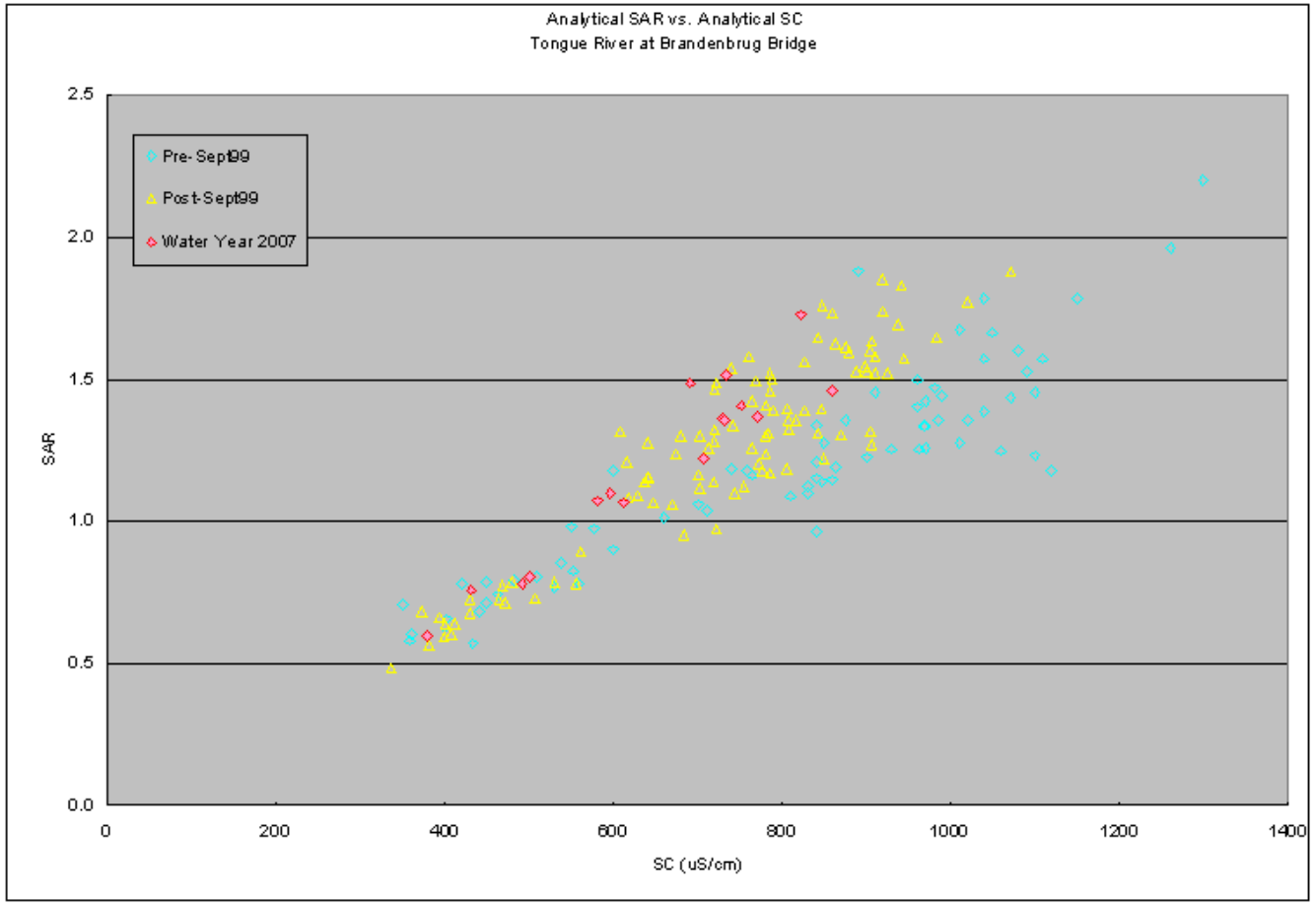


Figure 28 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River below Brandenburg Bridge. Historical SAR vs. SC data are also shown to place the data in context.

Figure 29: Tongue River above TY Diversion

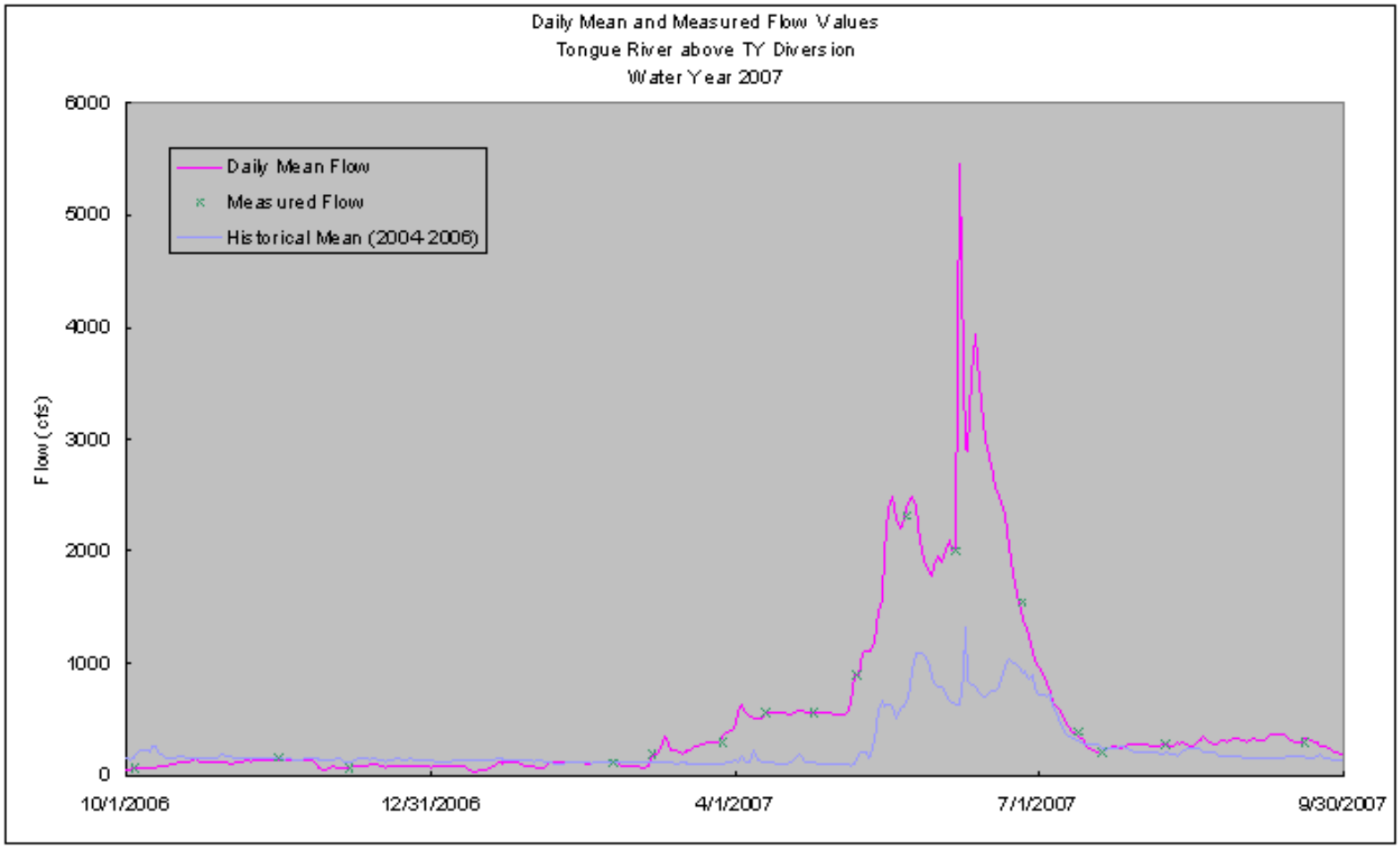
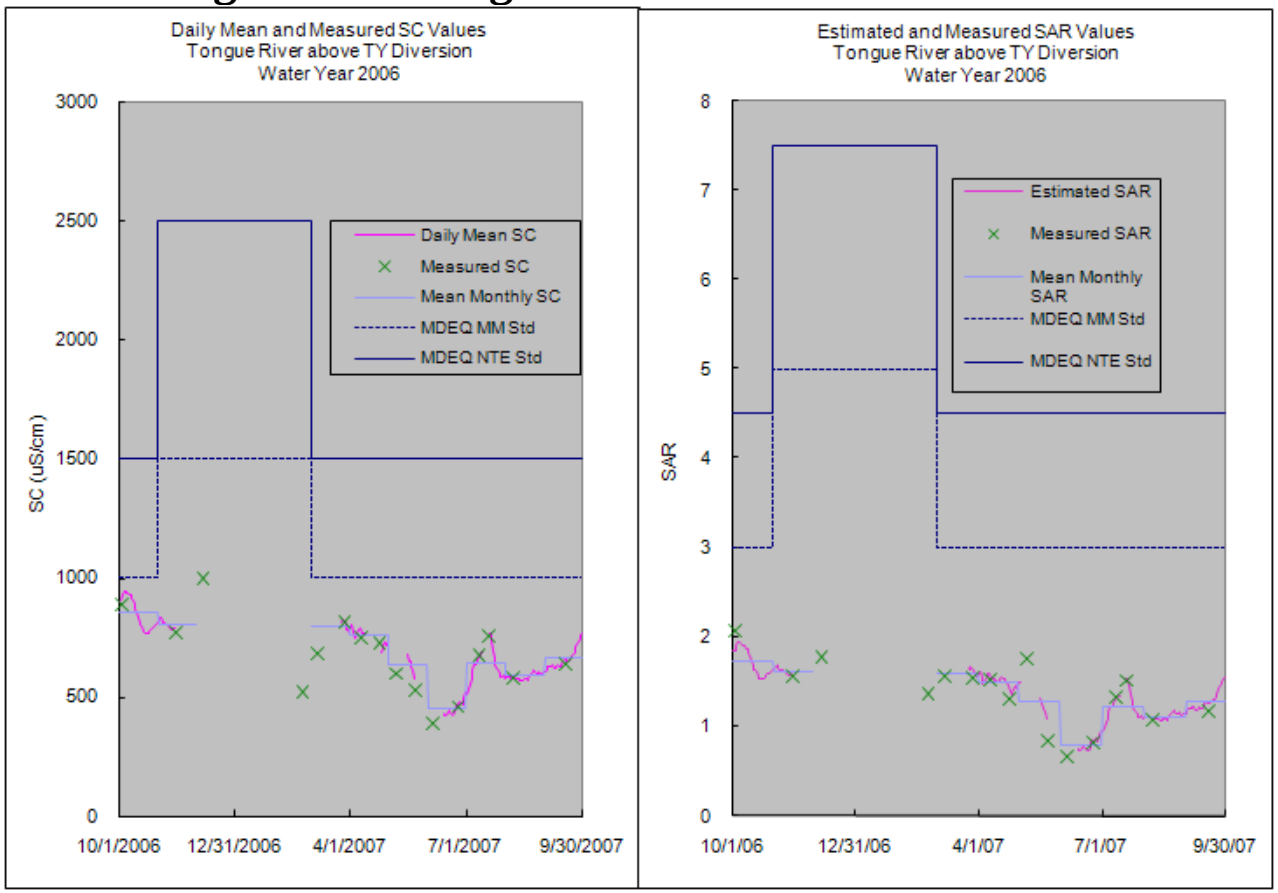


Figure 29 shows daily mean and field measurements of flow in a time series plot for water year 2007 for the Tongue River above the TY Diversion. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 40 to 5460 cfs. Cumulative 2007 flows were 203% of historical; however the historical record is rather short.

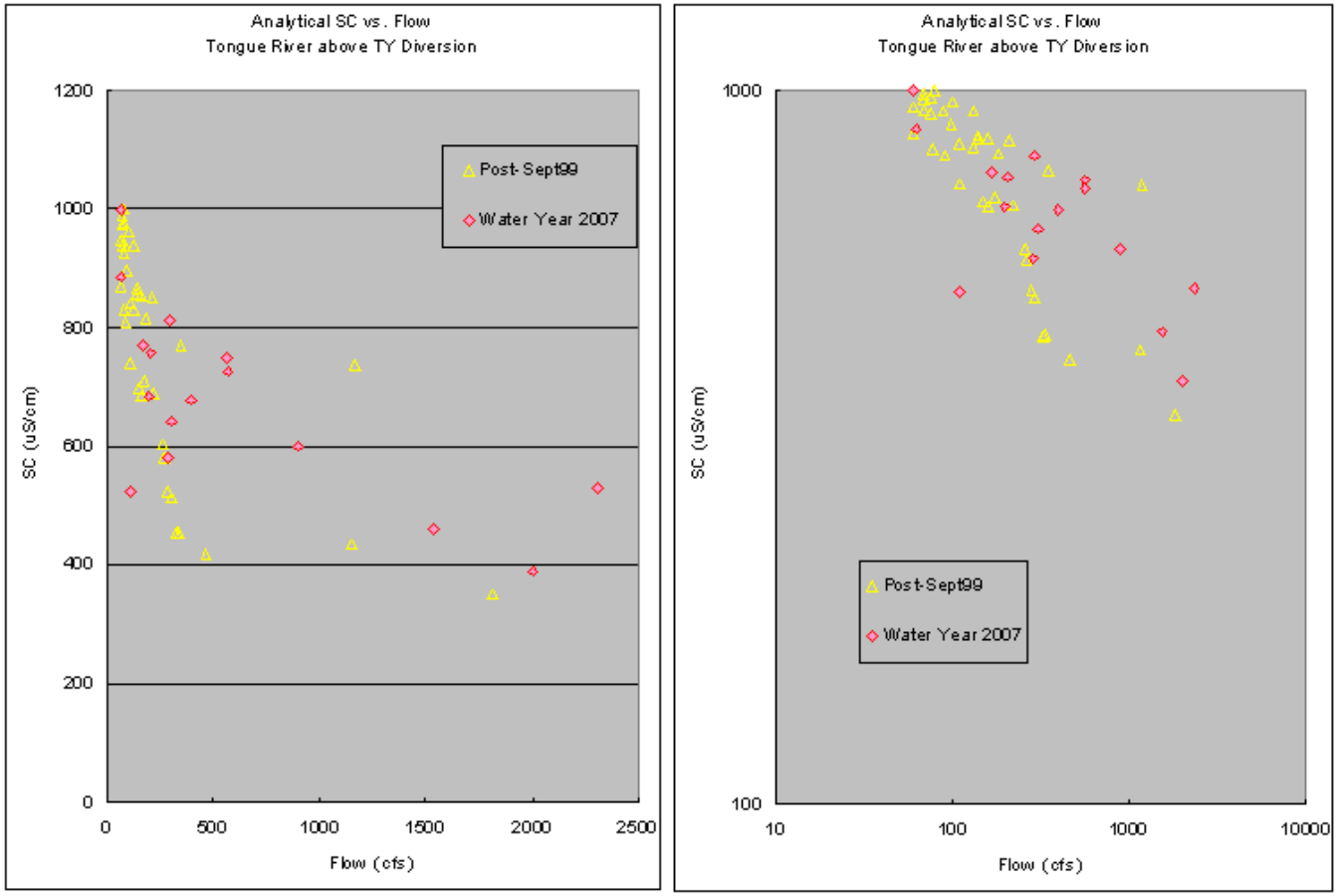
Figure 30: Tongue River above TY Diversion



A **B**

Figure 30 shows analytical and daily mean SC values (A) and analytical SAR values (B) in time series plots for water year 2007 for the Tongue River above the TY Diversion, near Miles City, MT. Mean Monthly SC values are also shown. SC values ranged from 390 to 998 uS/cm. Analytical SAR values ranged from 0.7 to 2.1. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. Measured and estimated values are below these standards for the entire year.

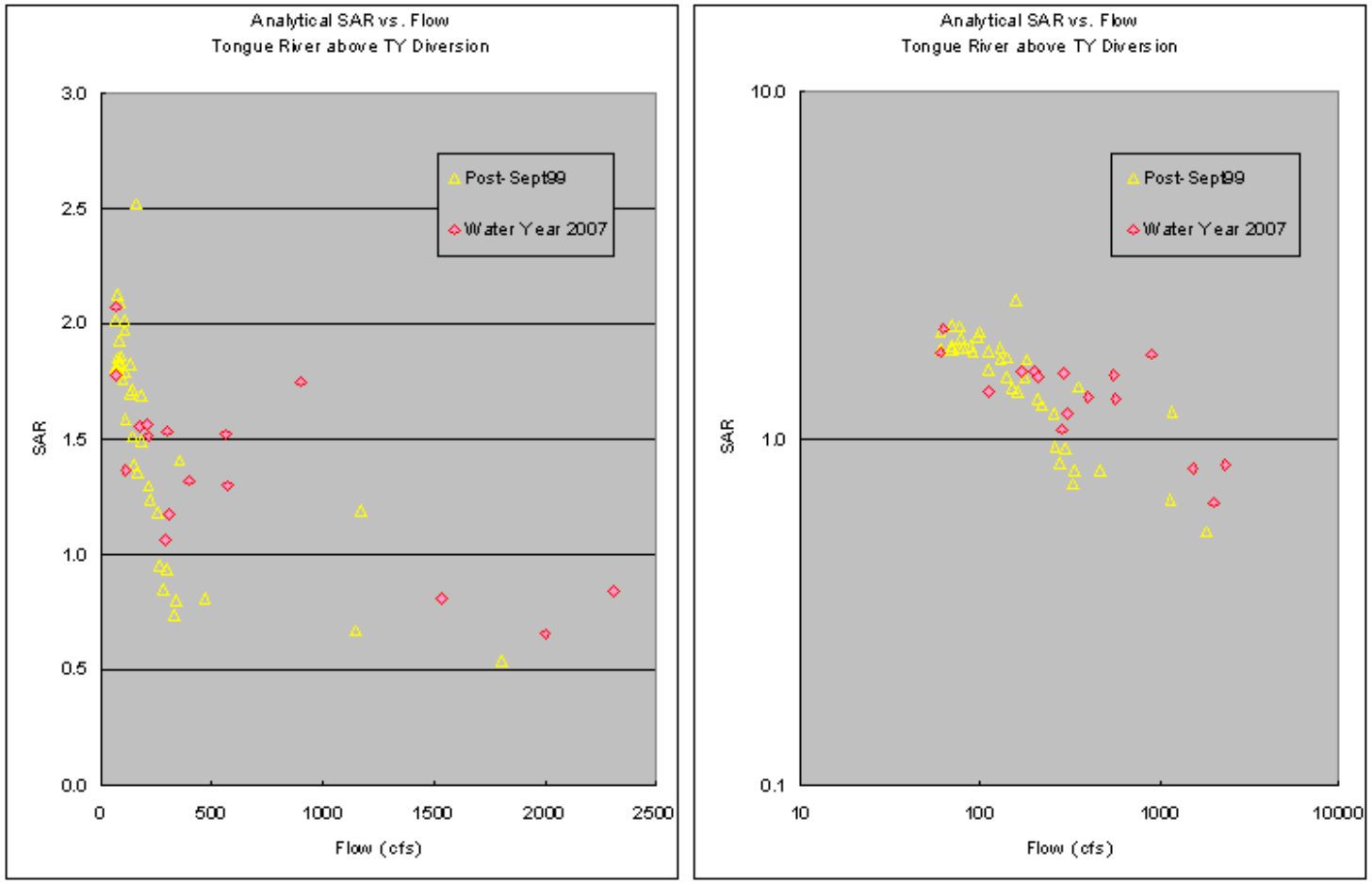
Figure 31: Tongue River above TY Diversion



A **B**

Figure 31 shows analytical SC vs. Flow data for water year 2007 for the Tongue River above the TY Diversion Dam, near Miles City, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 32: Tongue River above TY Diversion



A **B**

Figure 32 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River above the TY Diversion Dam, near Miles City, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 33: Tongue River above TY Diversion

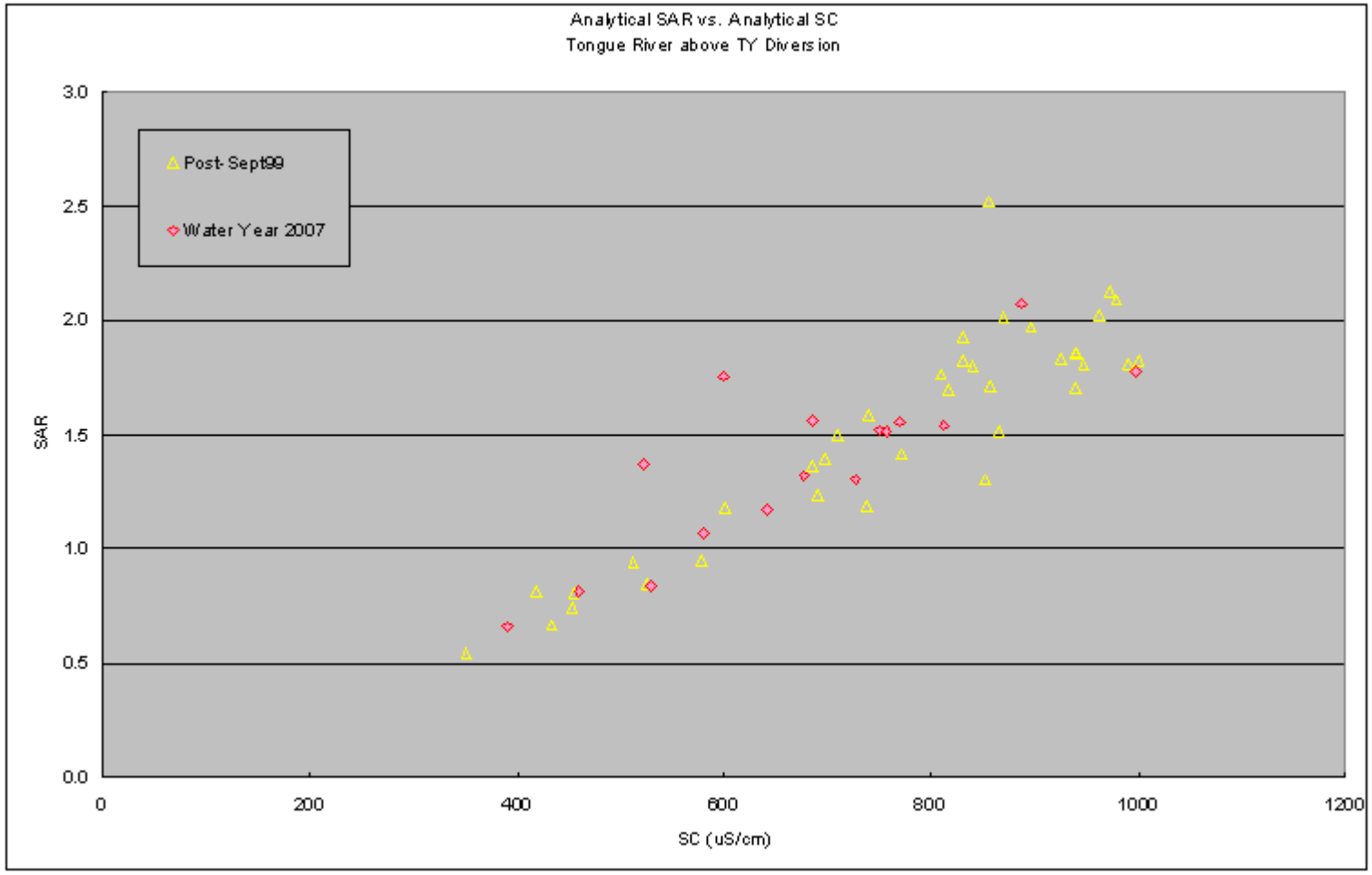


Figure 33 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River above the TY Diversion Dam, near Miles City, MT. Historical SAR vs. SC data are also shown to place the data in context.

Figure 34: Tongue River at Miles City, MT

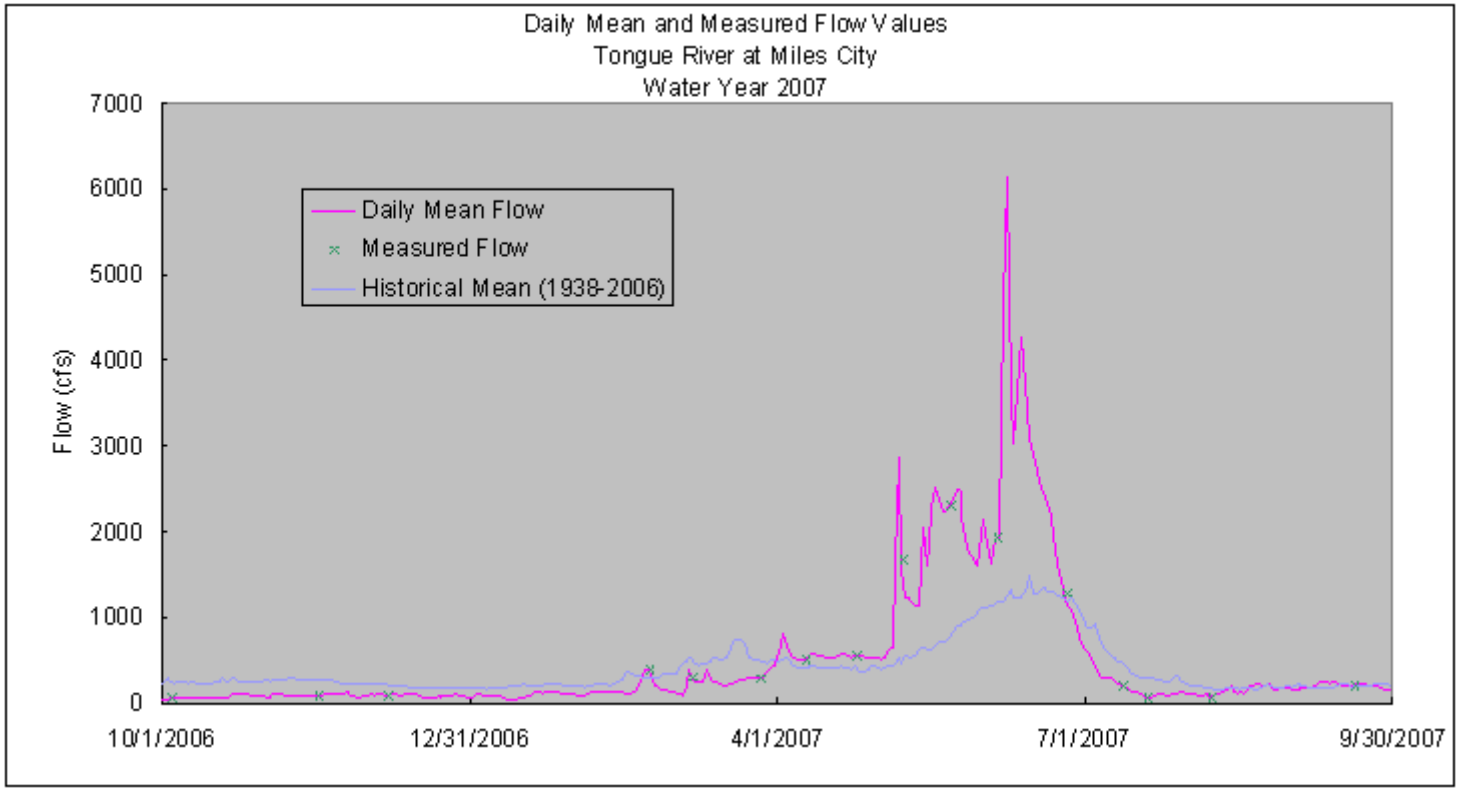
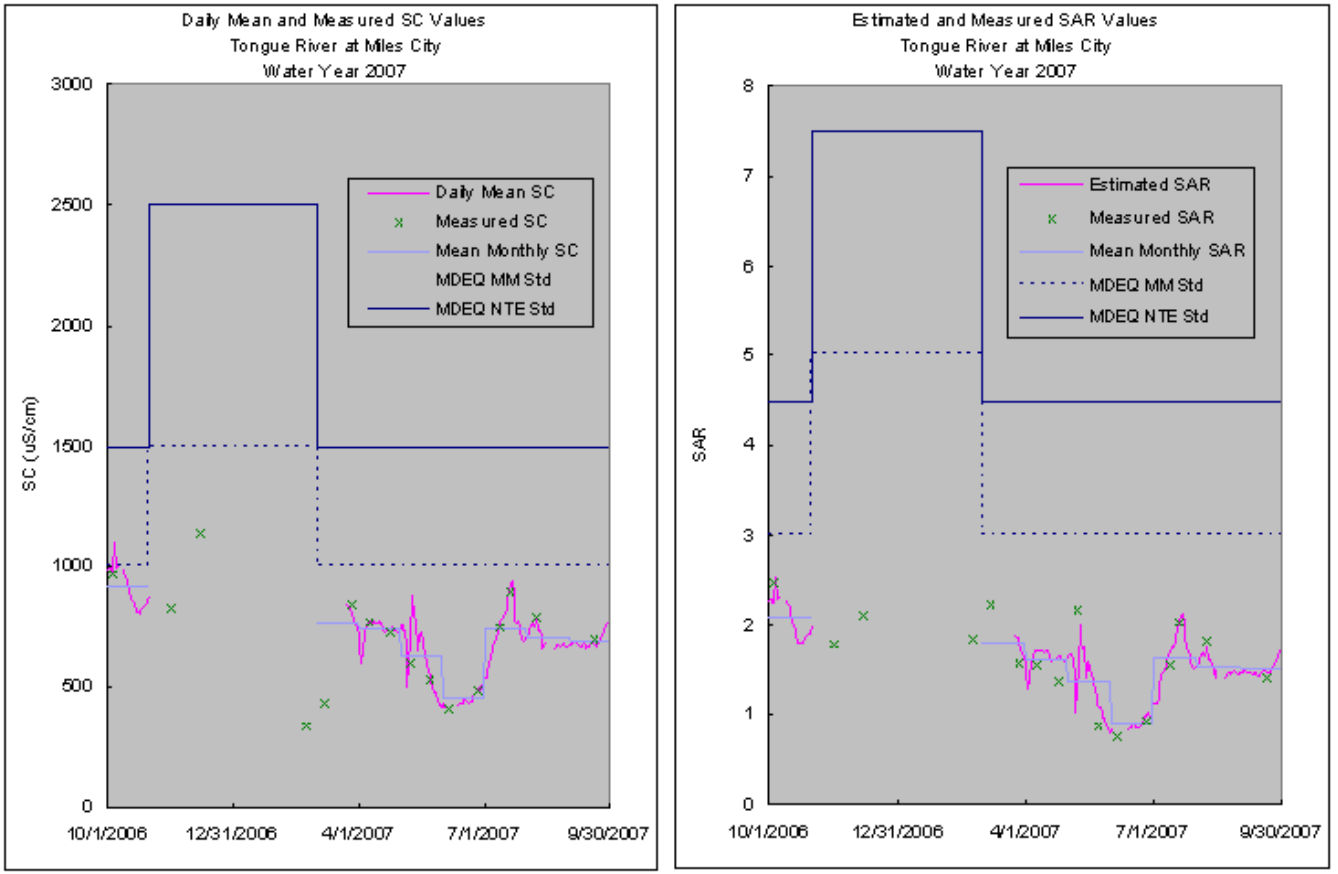


Figure 34 shows daily mean and field measurements of flow in a time series plot for water year 2007 for the Tongue River at Miles City, MT. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 48 to 6130 cfs. Cumulative 2007 flows were 125% of historical.

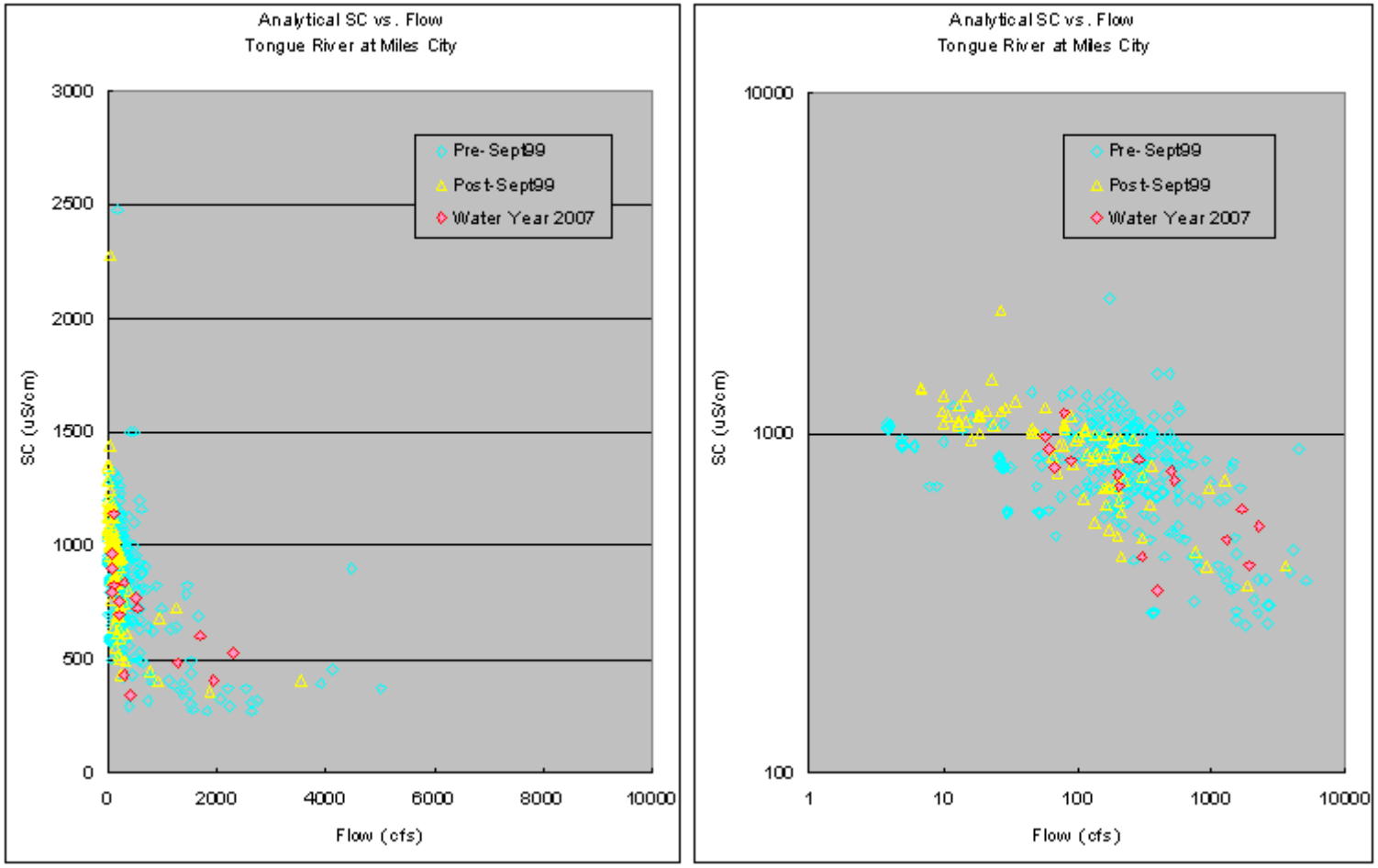
Figure 35: Tongue River at Miles City, MT



A **B**

Figure 35 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for the Tongue River at Miles City, MT. Mean Monthly SC and SAR values are also shown. SC values ranged from 342 to 1140 uS/cm. SAR values ranged from 0.8 to 2.5. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. Measured and estimated values are below these standards for the entire year.

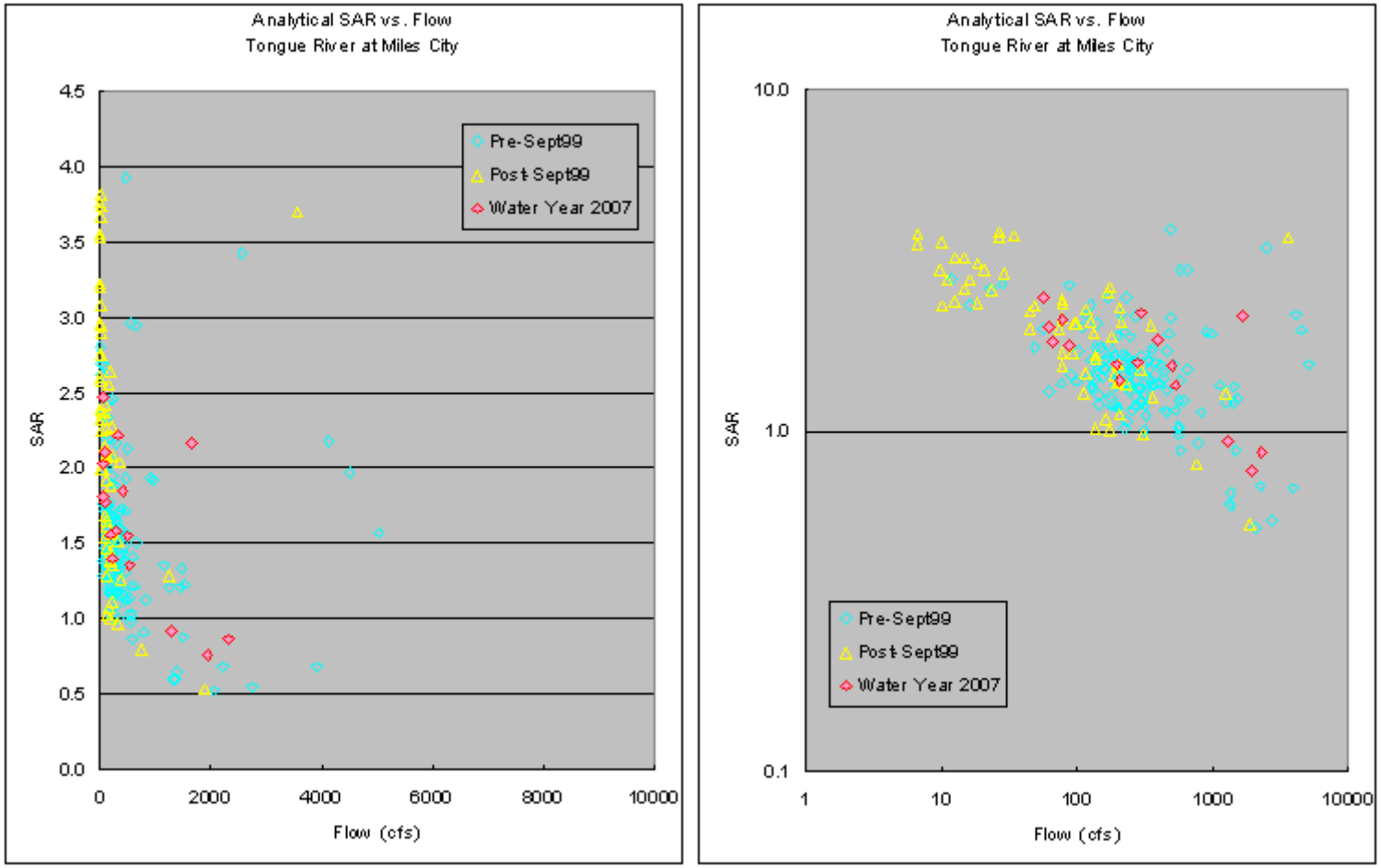
Figure 36: Tongue River at Miles City, MT



A **B**

Figure 36 shows analytical SC vs. Flow data for water year 2007 for the Tongue River at Miles City, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 37: Tongue River at Miles City, MT



A **B**

Figure 37 shows analytical SAR vs. Flow data for water year 2007 for the Tongue River at Miles City, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 38: Tongue River at Miles City, MT

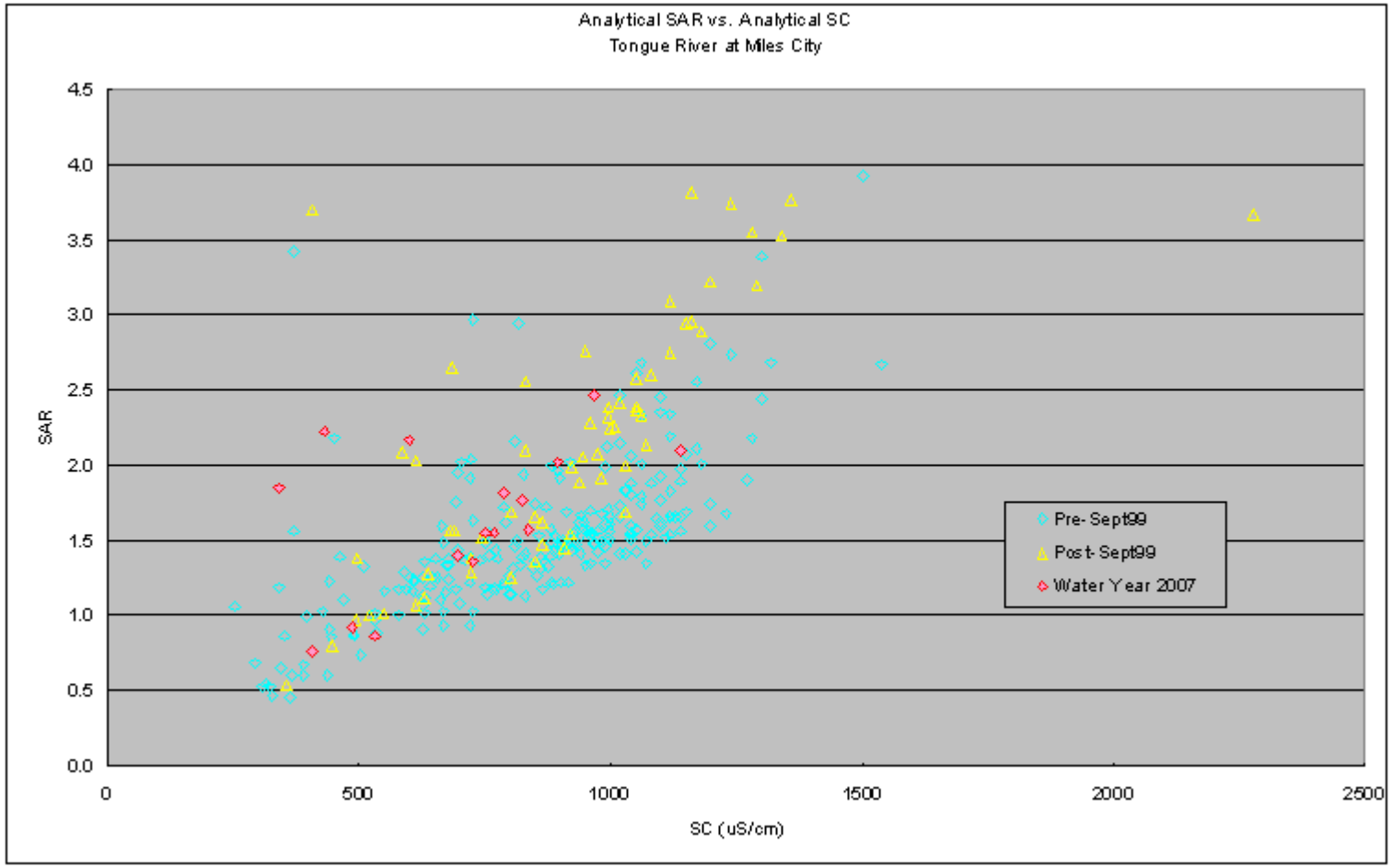


Figure 38 shows analytical SAR vs. analytical SC data for water year 2007 for the Tongue River at Miles City. Historical SAR vs. SC data are also shown to place the data in context.

Figure 39: Goose Creek near Acme, WY

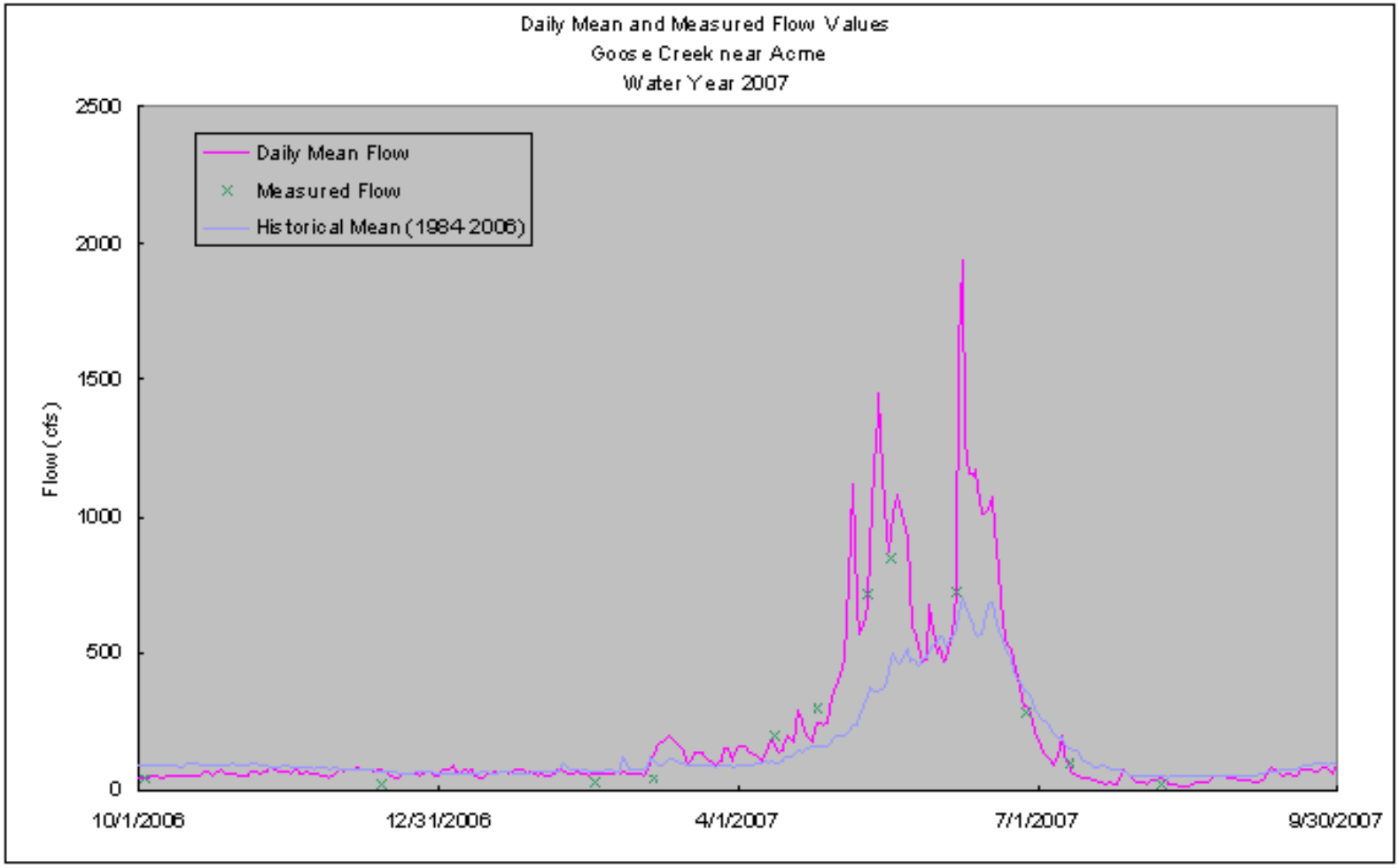
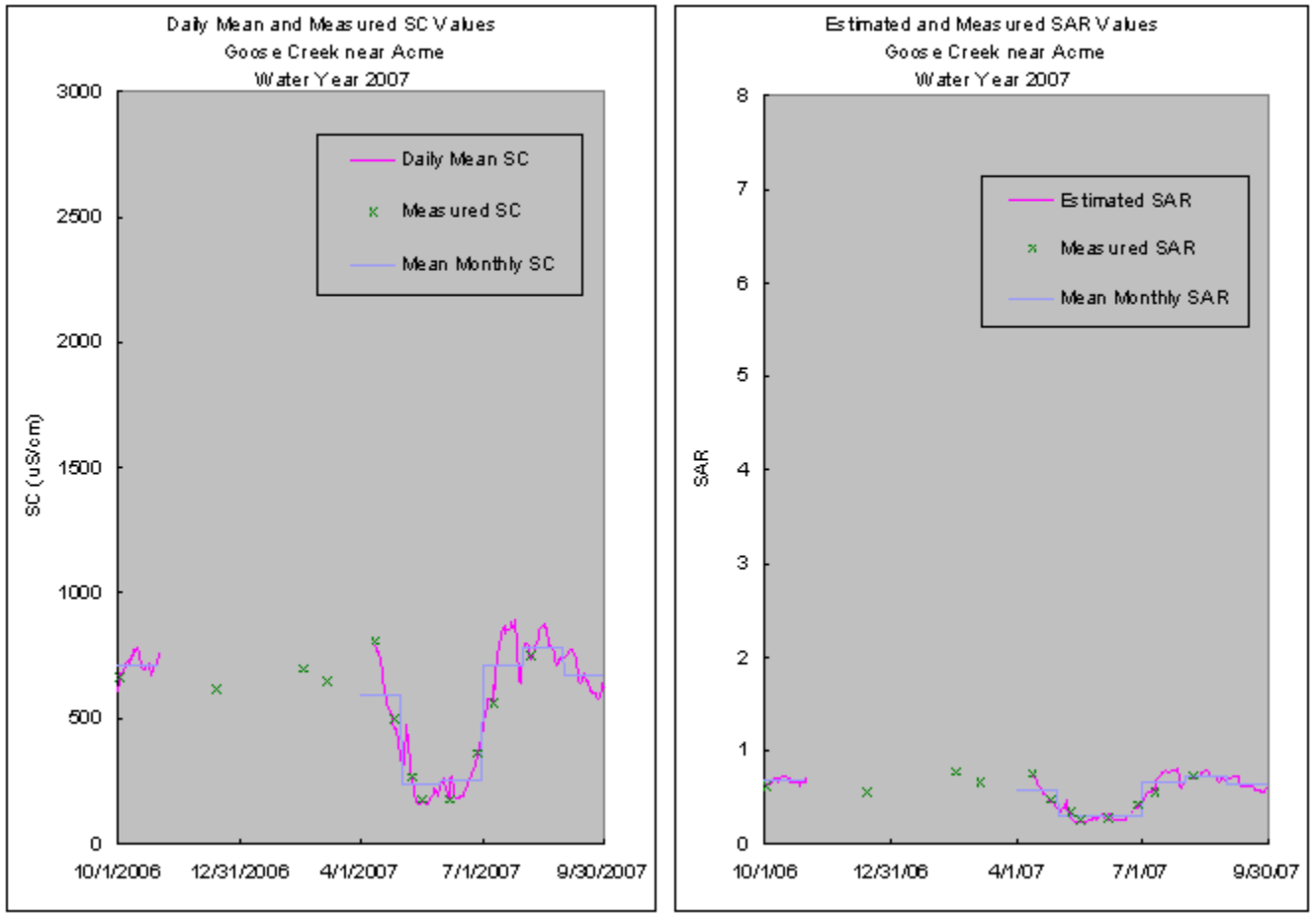


Figure 39 shows daily mean and field measurements of flow in a time series plot for water year 2007 for Goose Creek near Acme. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 16 to 1940 cfs. Cumulative 2007 flows were 131% of historical.

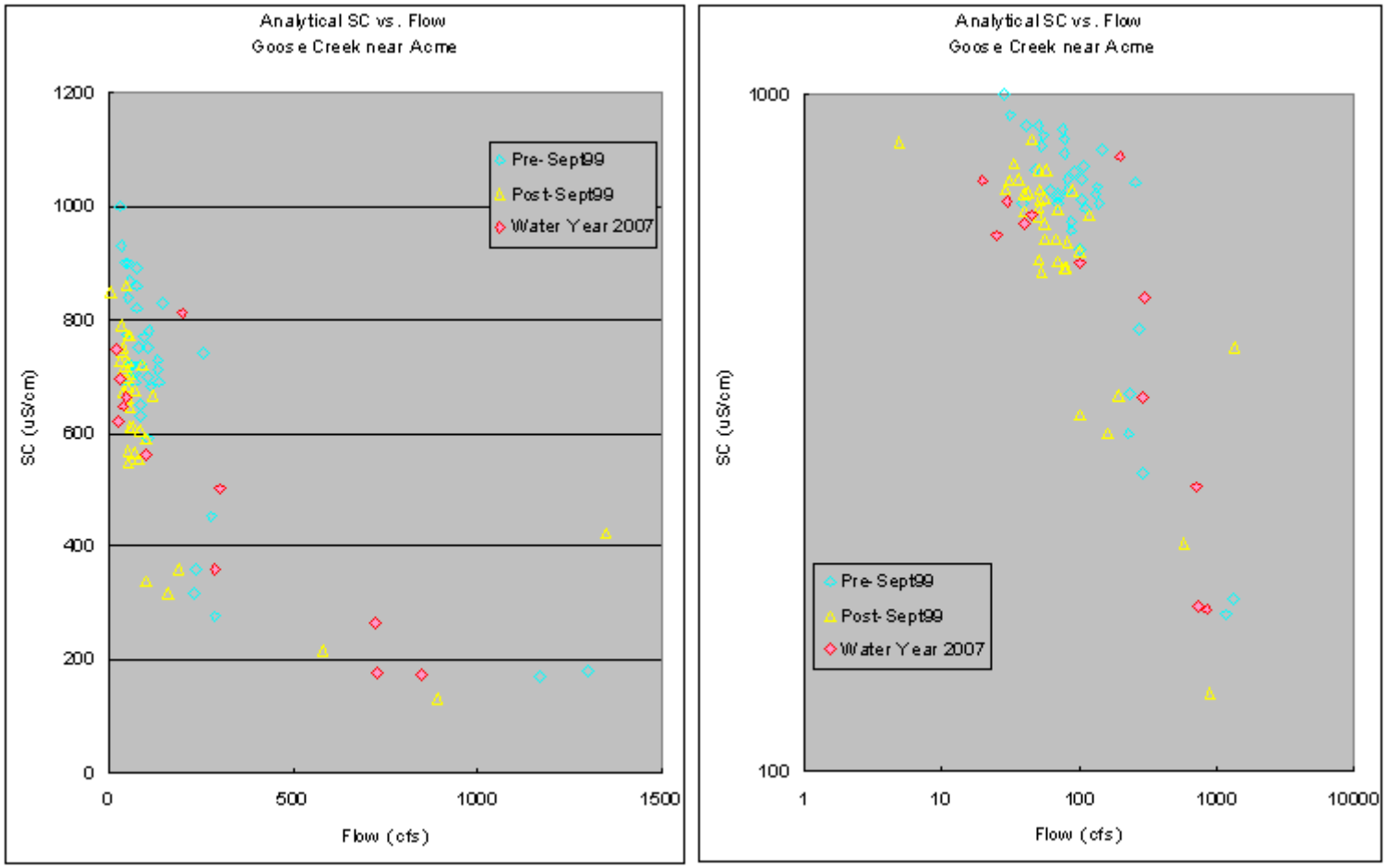
Figure 40: Goose Creek near Acme, WY



A **B**

Figure 40 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for Goose Creek near Acme, WY. Mean Monthly EC and SAR values are also shown. SC values ranged from 152 to 890 uS/cm. SAR values ranged from 0.2 to 0.8.

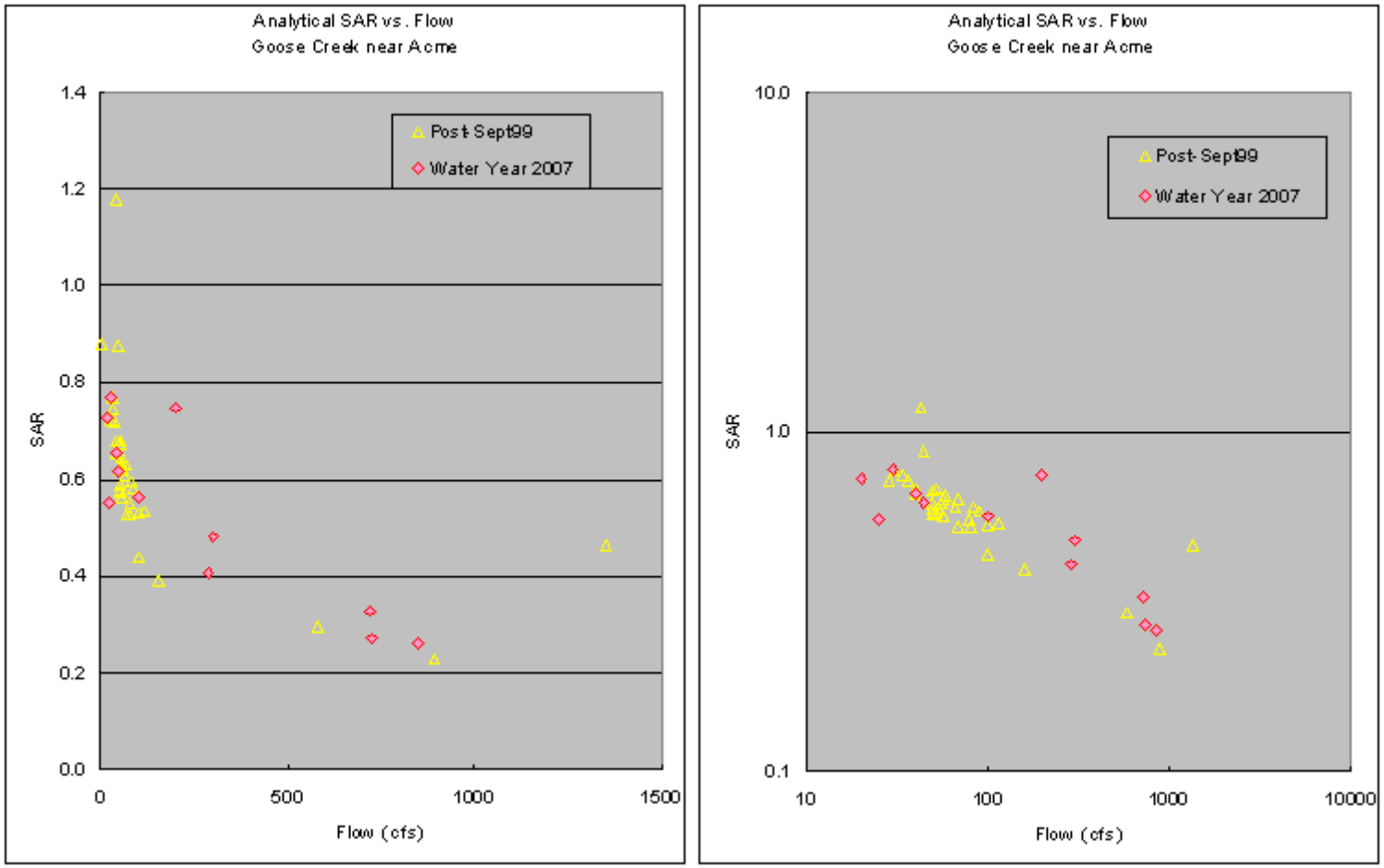
Figure 41: Goose Creek near Acme, WY



A **B**

Figure 41 shows analytical SC vs. Flow data for water year 2007 for Goose Creek near Acme, WY. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 42: Goose Creek near Acme, WY



A **B**

Figure 42 shows analytical SAR vs. Flow data for water year 2007 for Goose Creek near Acme, WY. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 43: Goose Creek near Acme, WY

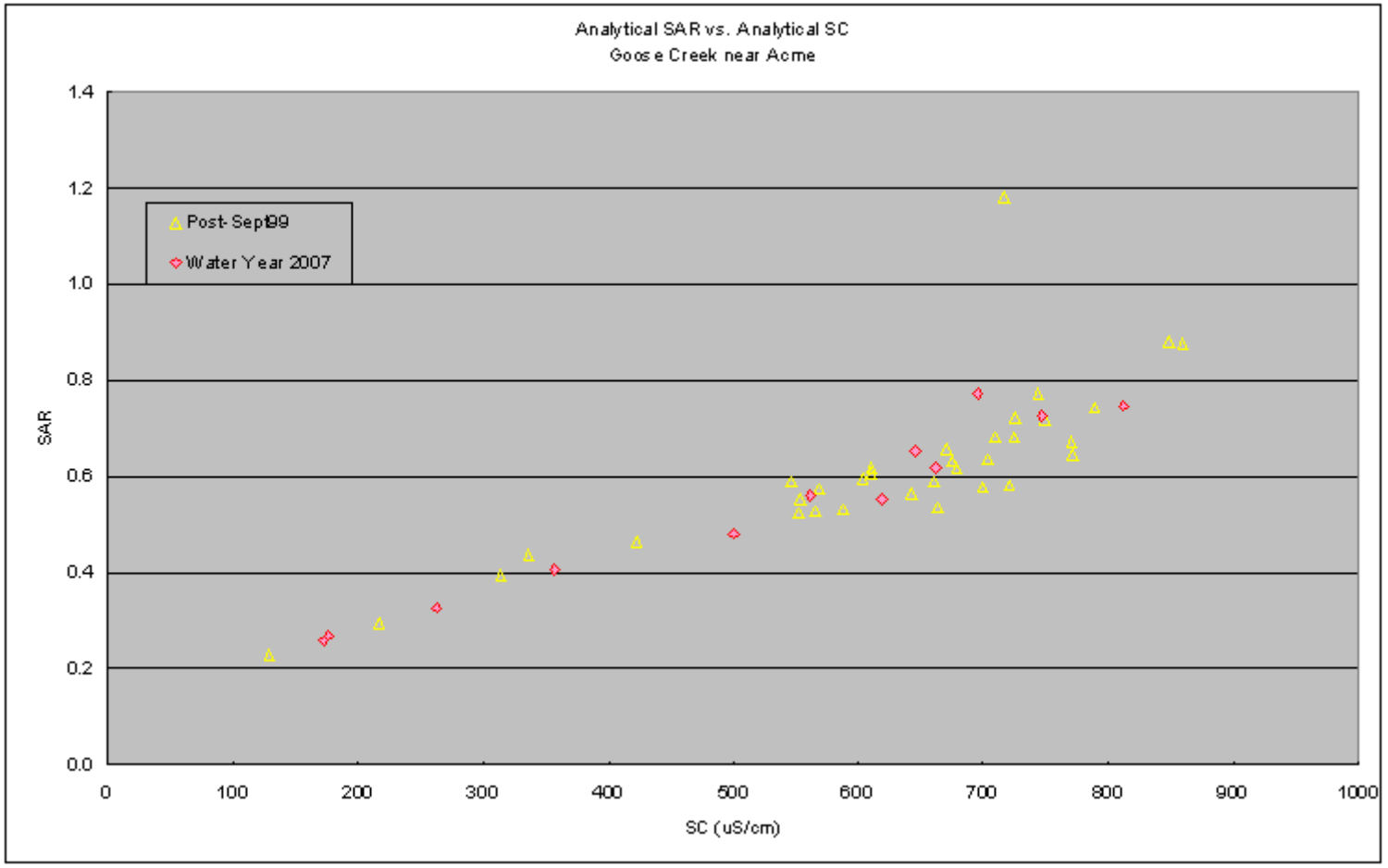


Figure 43 shows analytical SAR vs. analytical SC data for water year 2007 for Goose Creek near Acme, WY. Historical SAR vs. SC data are also shown to place the data in context.

Figure 44: Prairie Dog Creek near Acme, WY

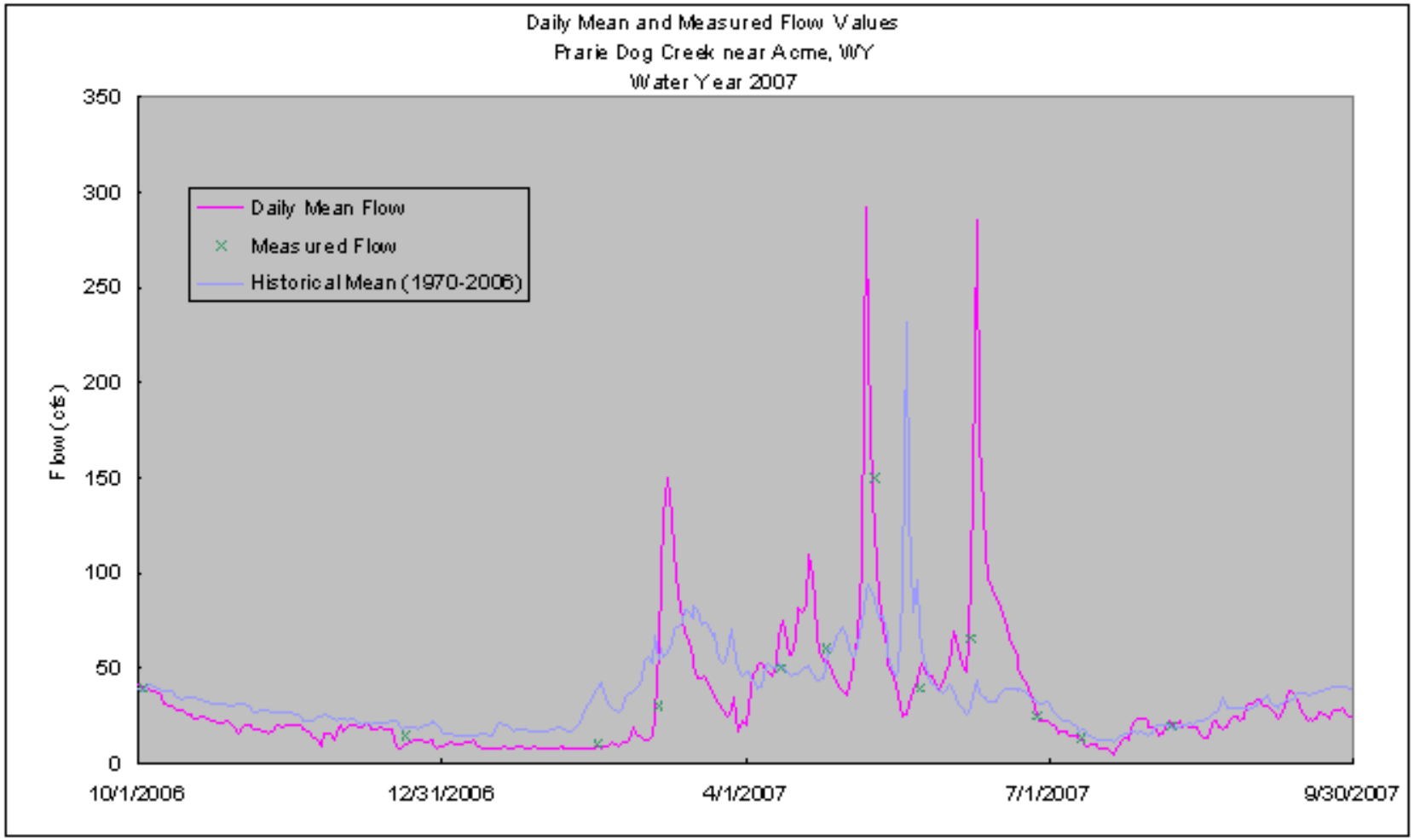
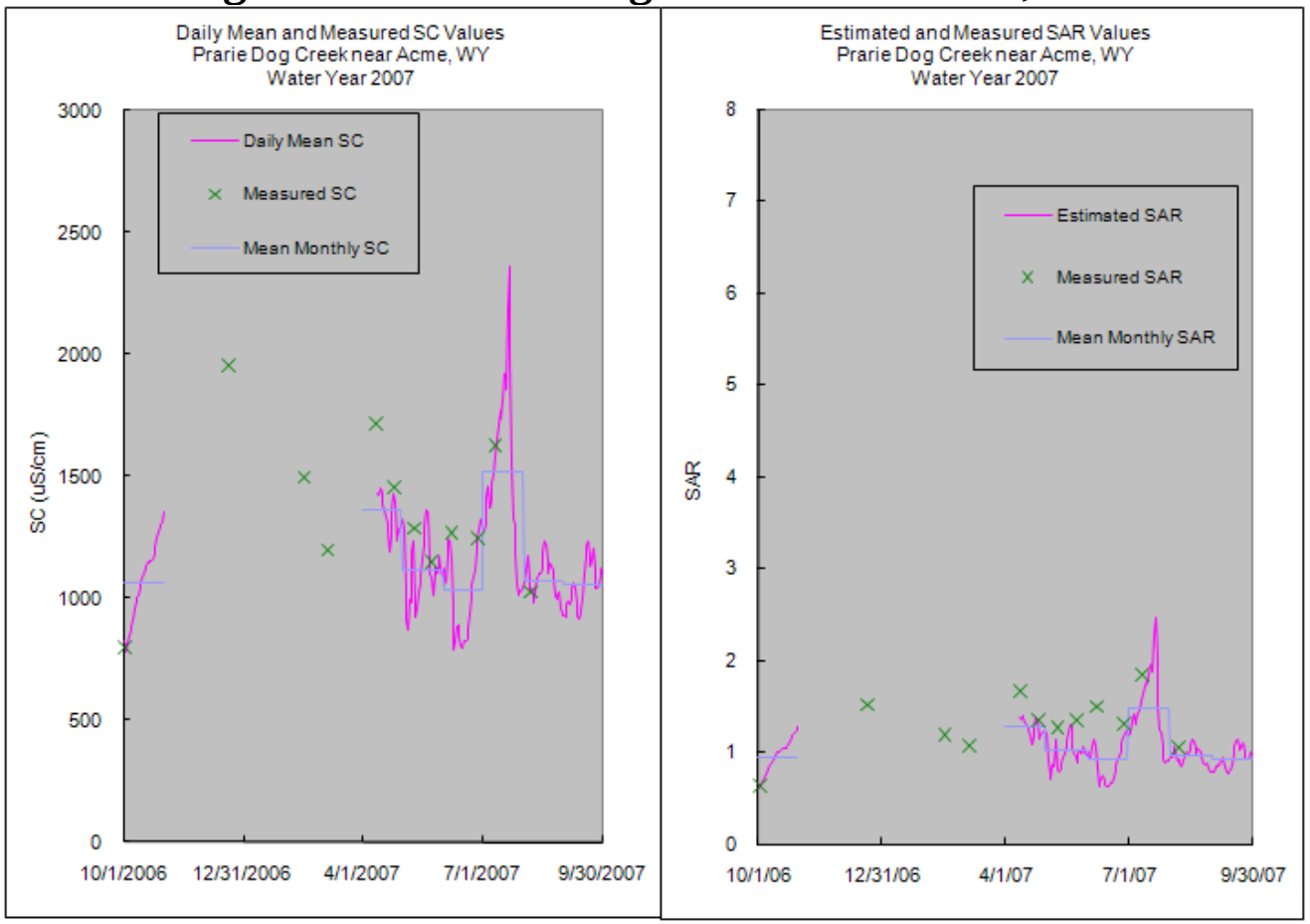


Figure 44 shows daily mean and field measurements of flow in a time series plot for water year 2007 for Prairie Dog Creek near Acme. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 4.6 to 292 cfs. Cumulative 2007 flows were 93% of historical.

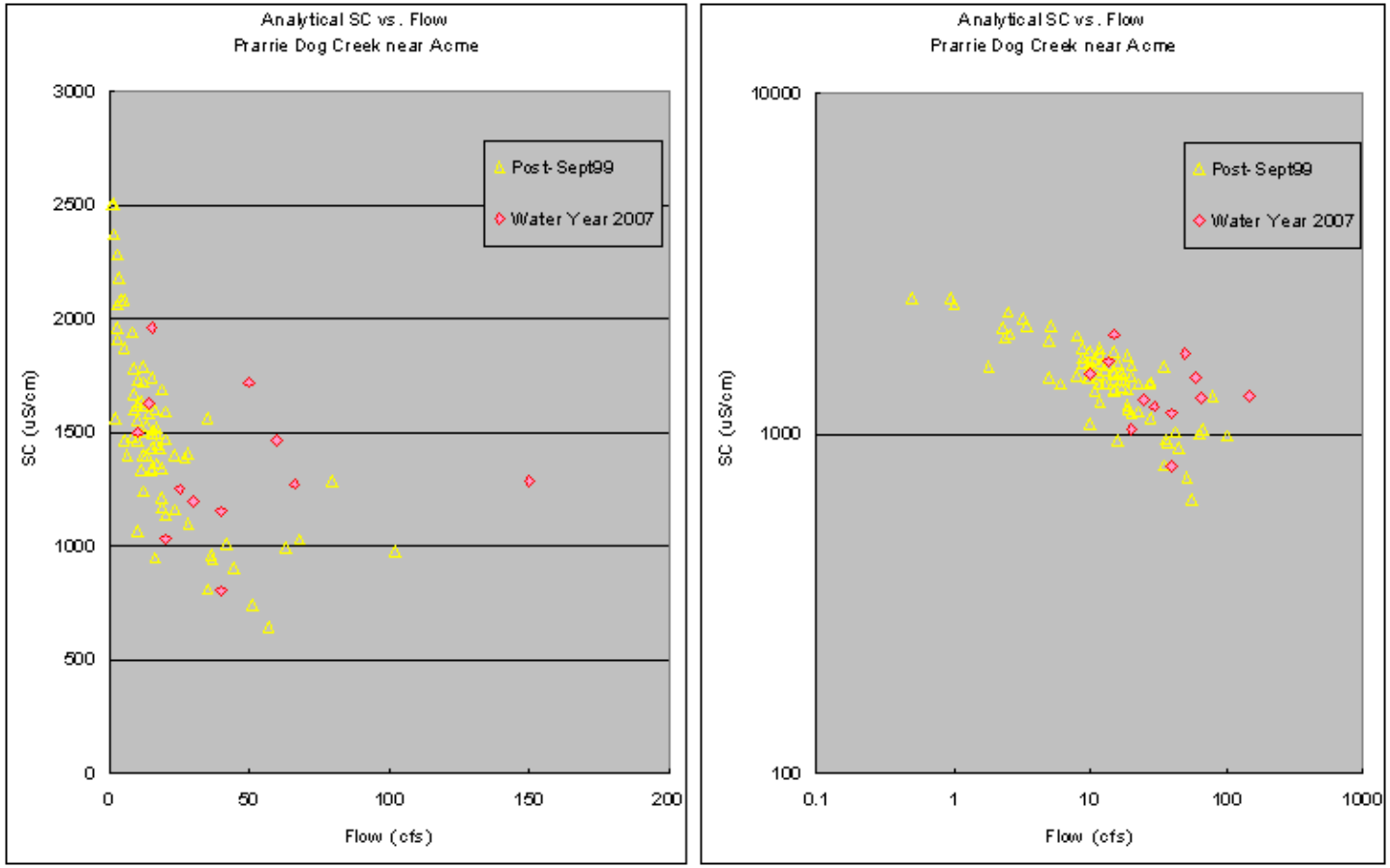
Figure 45: Prairie Dog Creek near Acme, WY



A **B**

Figure 45 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for Prairie Dog Creek near Acme, WY. Mean Monthly SC and SAR values are also shown. SC values ranged from 777 to 2360 uS/cm. SAR values ranged from 0.6 to 2.5.

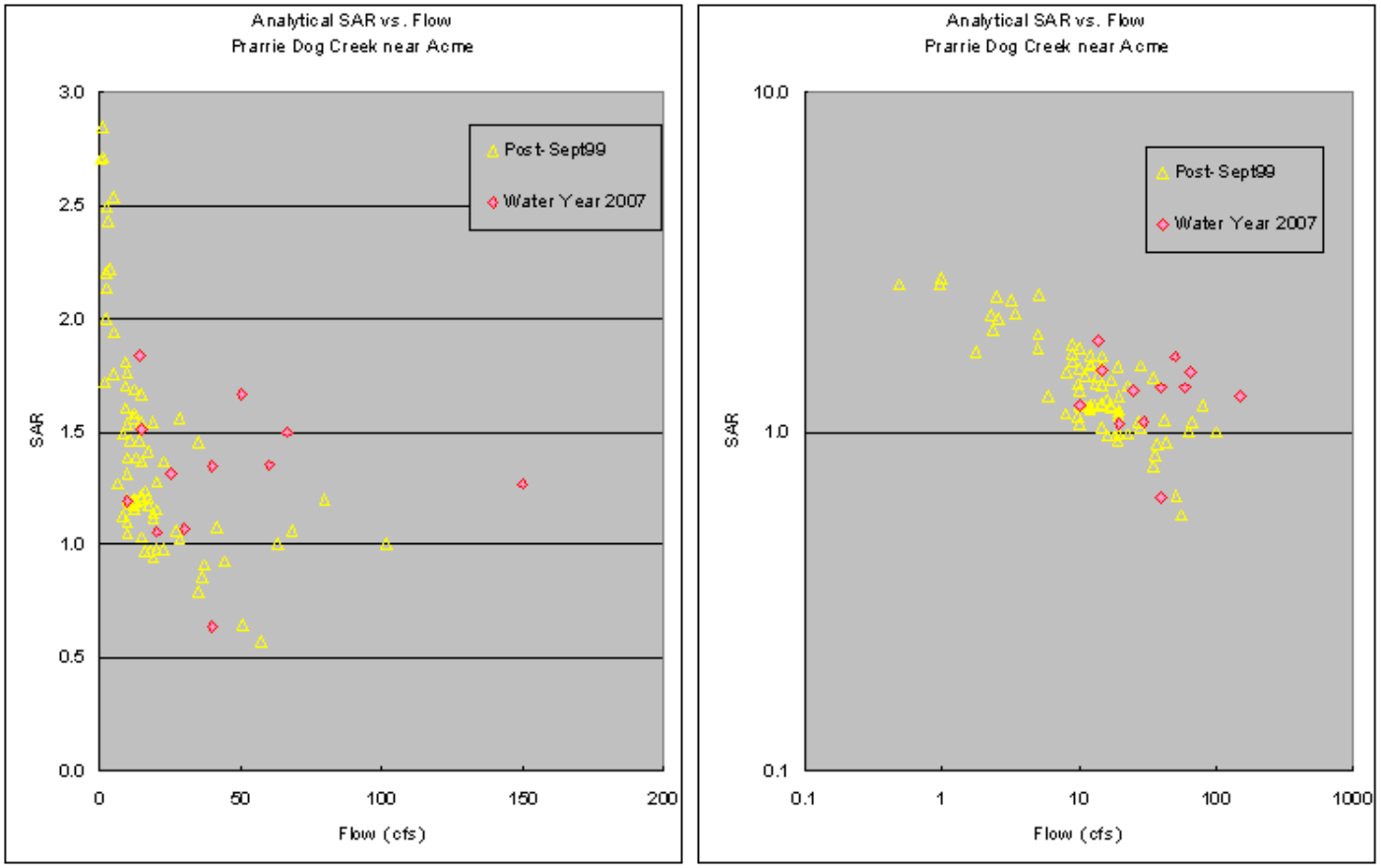
Figure 46: Prairie Dog Creek near Acme, WY



A **B**

Figure 46 shows analytical SC vs. Flow data for water year 2007 for Prairie Dog Creek near Acme, WY. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 47: Prairie Dog Creek near Acme, WY



A **B**

Figure 47 shows analytical SAR vs. Flow data for water year 2007 for Prairie Dog Creek near Acme, WY. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 48: Prairie Dog Creek near Acme, WY

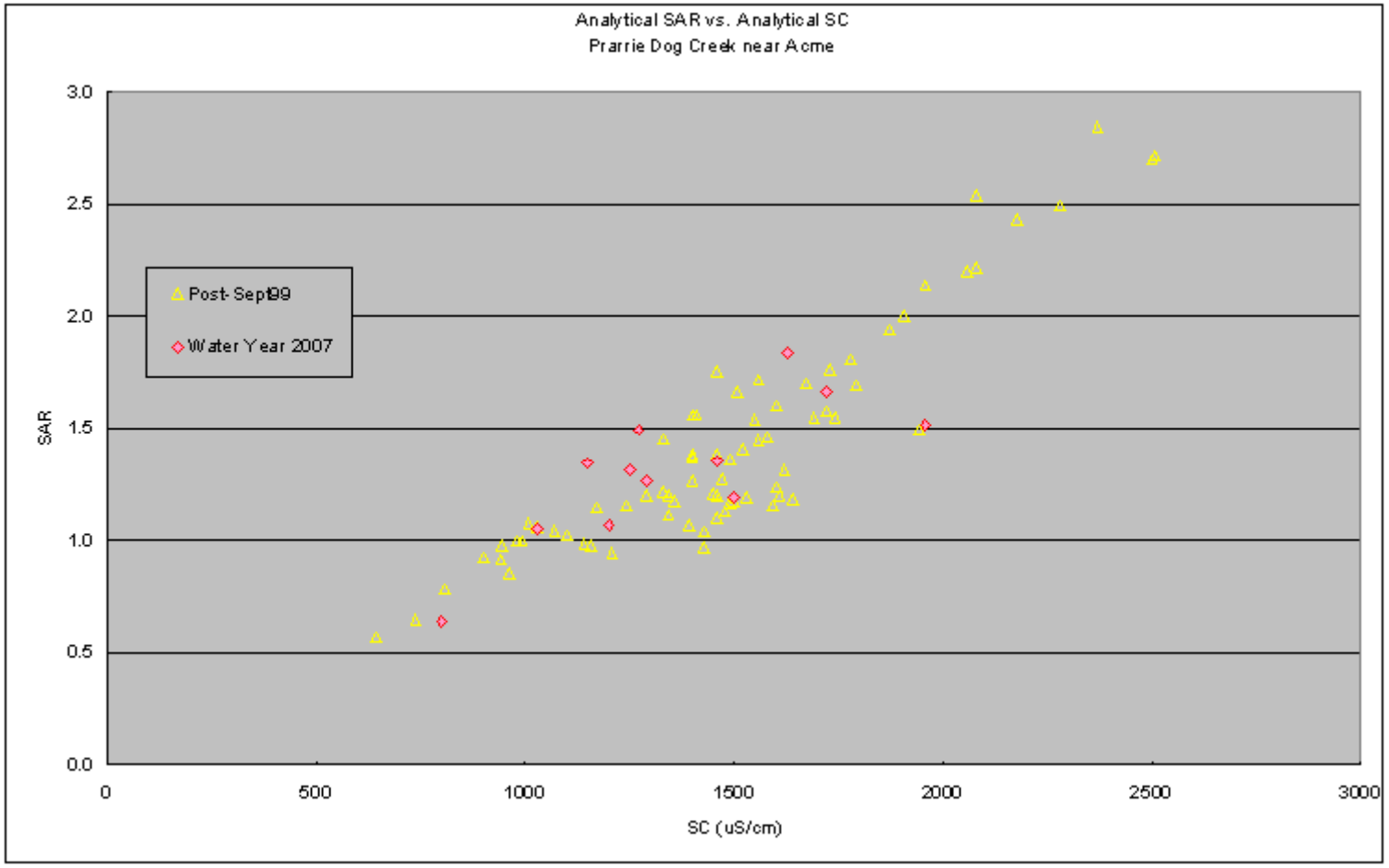


Figure 48 shows analytical SAR vs. analytical SC data for water year 2007 for Prairie Dog Creek near Acme, WY. Historical SAR vs. SC data are also shown to place the data in context.

Figure 49: Hanging Woman Creek near Birney, MT

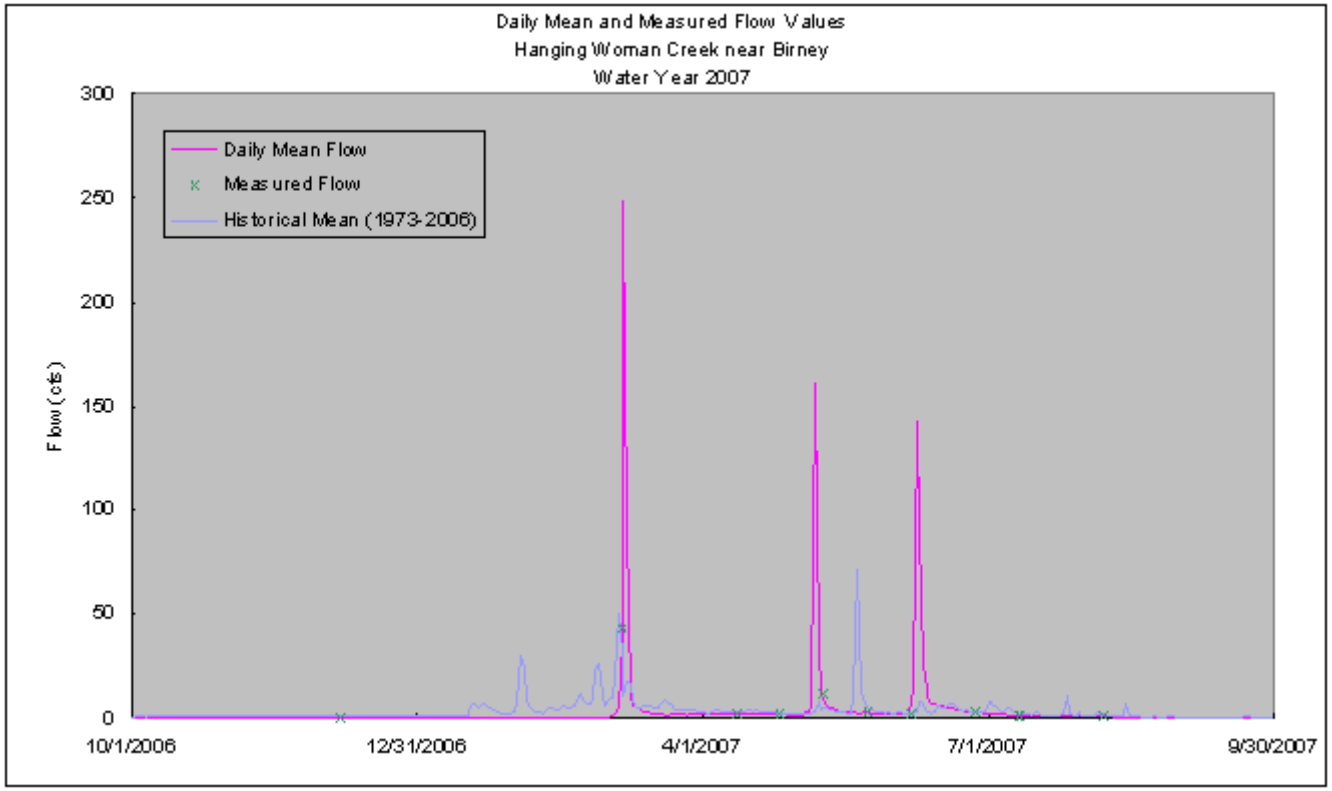
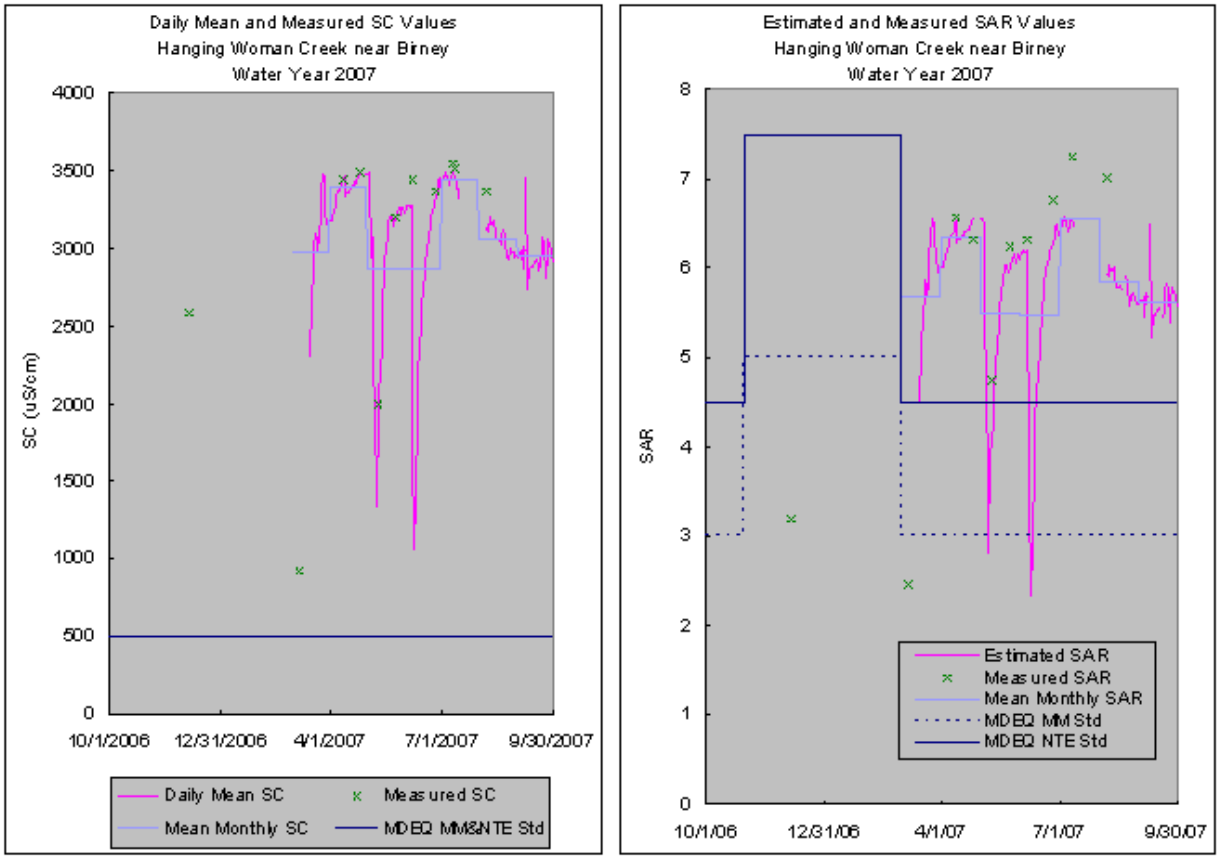


Figure 49 shows daily mean and field measurements of flow in a time series plot for water year 2007 for Hanging Woman Creek near Birney, MT. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 0 to 248 cfs. Cumulative 2007 flows were 105% of historical.

Figure 50: Hanging Woman Creek near Birney, MT



A **B**

Figure 50 shows analytical and daily mean SC values (A) and analytical and daily mean estimated SAR values (B) in time series plots for water year 2007 for Hanging Woman Creek near Birney, MT. Mean Monthly SC and SAR values are also shown. SC values ranged from 921 to 3540 uS/cm. SAR values ranged from 2.3 to 7.2. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. SC values were in excess of the EC standards for the entire year. SAR values were often above the standards.

Figure 51: Hanging Woman Creek near Birney, MT

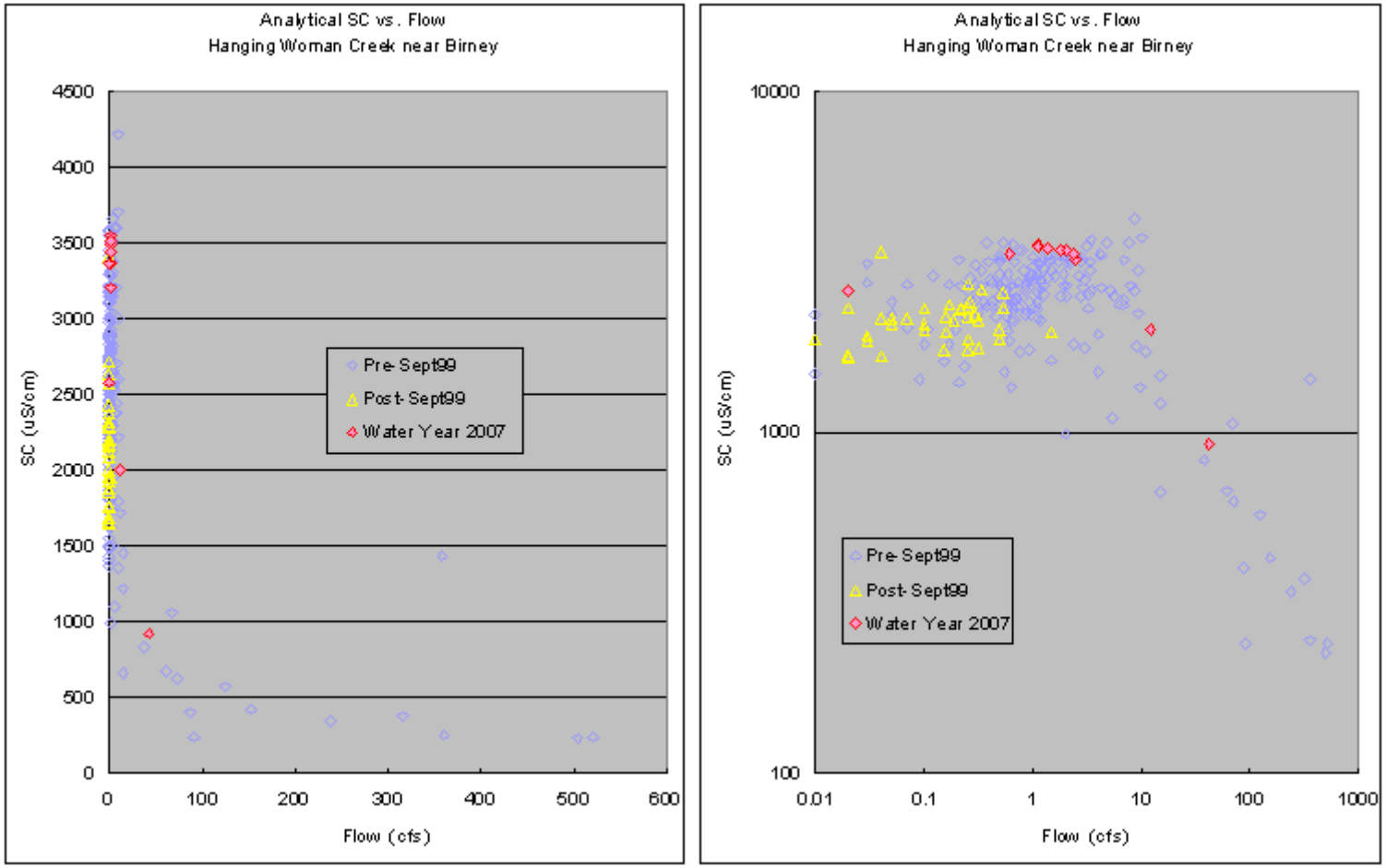
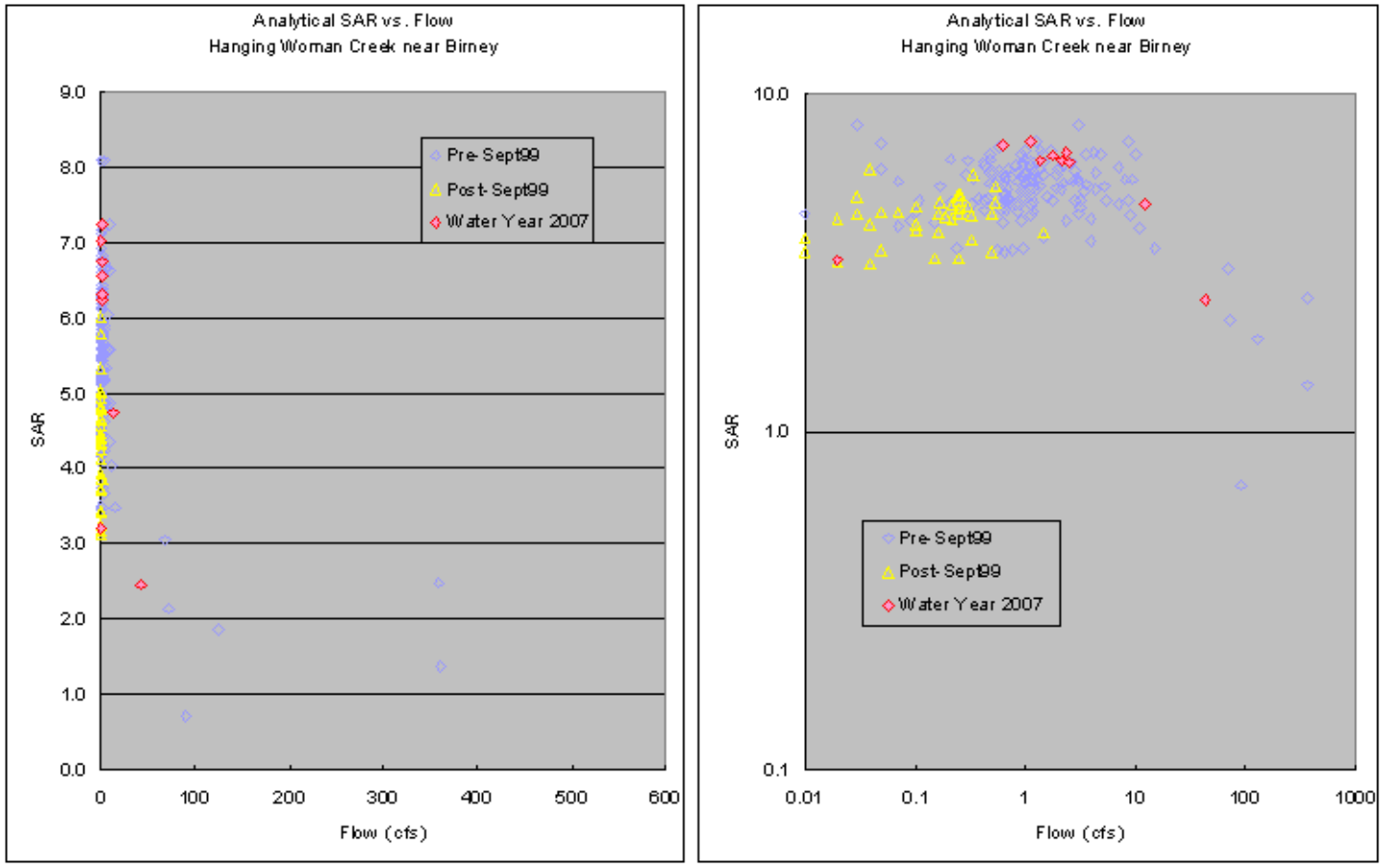


Figure 51 shows analytical SC vs. Flow data for water year 2007 for Hanging Woman Creek near Birney, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 52: Hanging Woman Creek near Birney, MT



A **B**

Figure 52 shows analytical SAR vs. Flow data for water year 2007 for Hanging Woman Creek near Birney, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 53: Hanging Woman Creek near Birney, MT

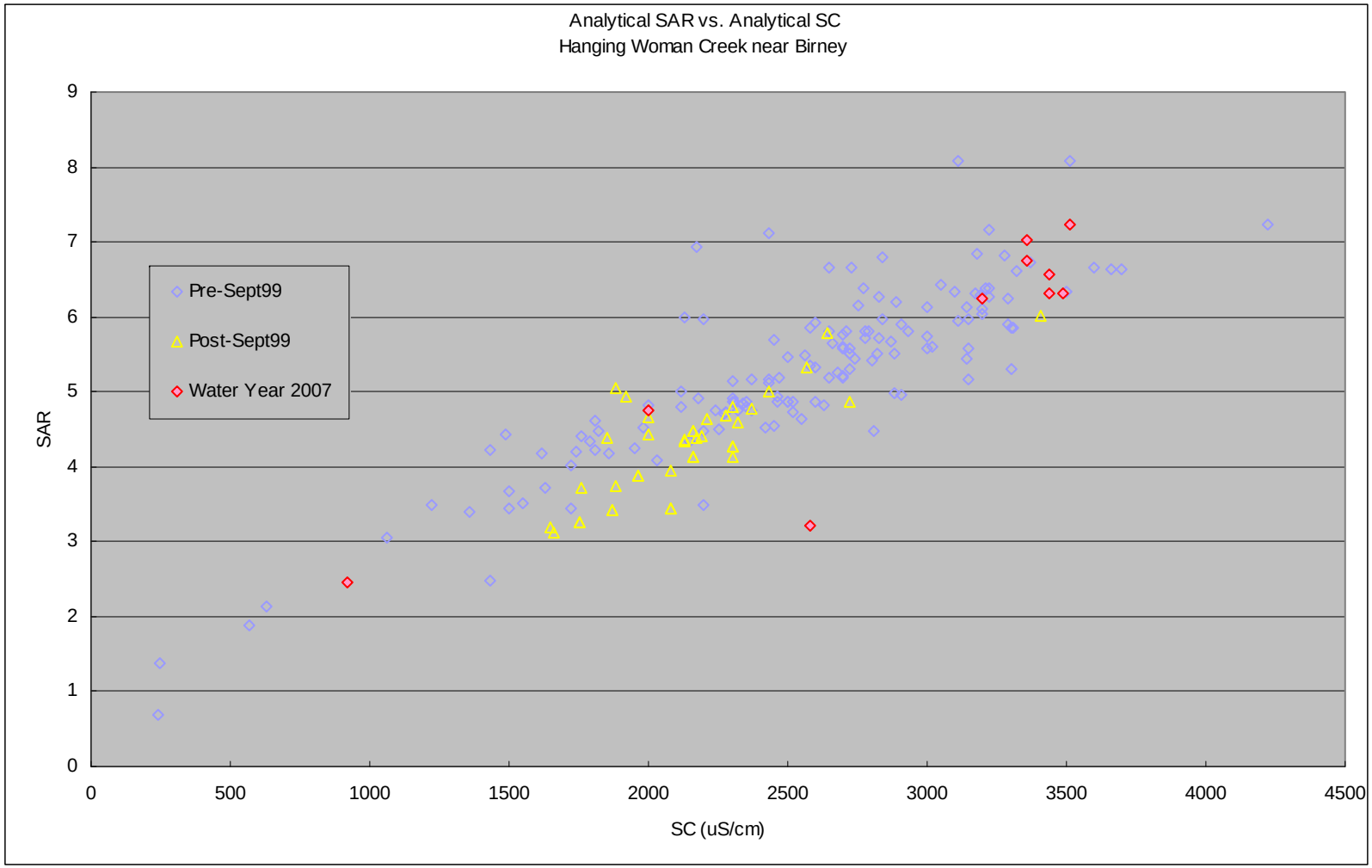


Figure 53 shows analytical SAR vs. analytical SC data for water year 2007 for Hanging Woman Creek near Birney, MT. Historical SAR vs. SC data are also shown to place the data in context.

Figure 54: Otter Creek at Ashland, MT

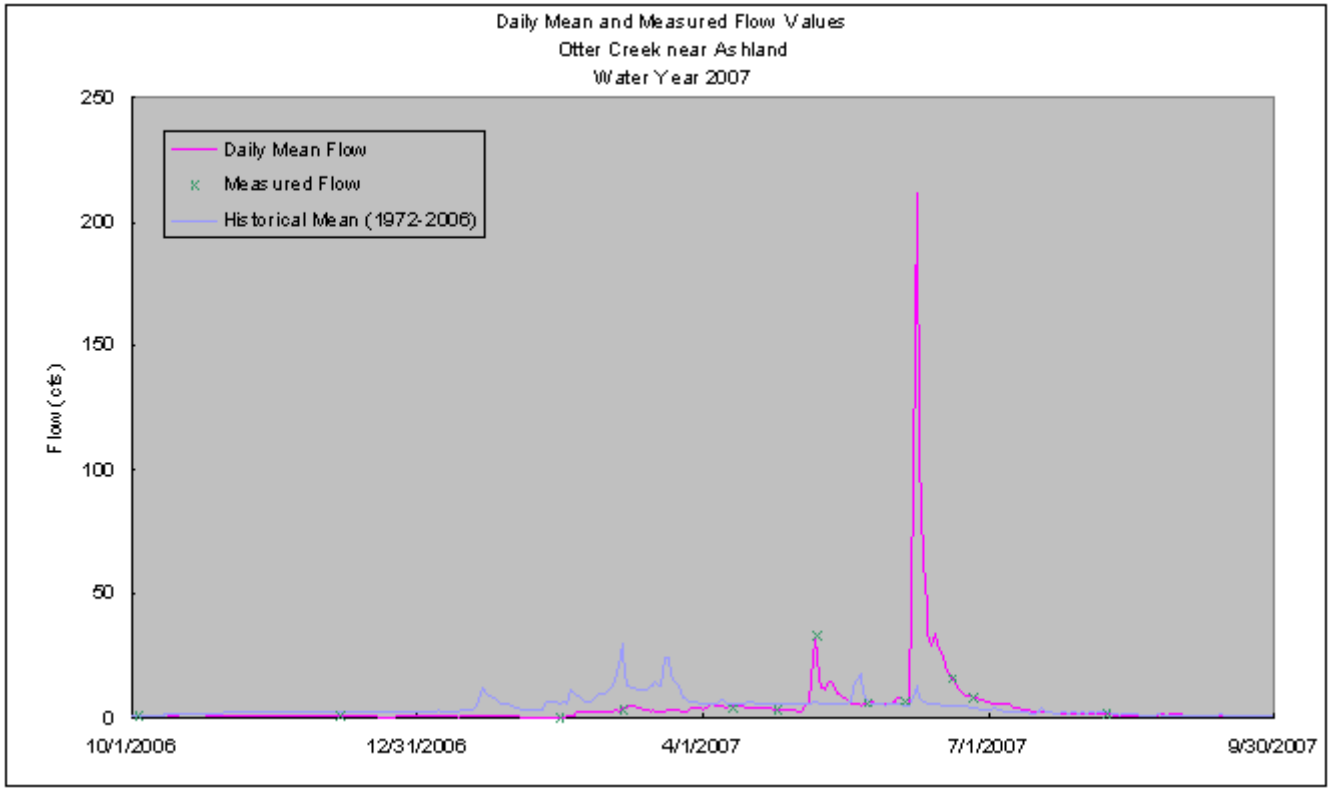
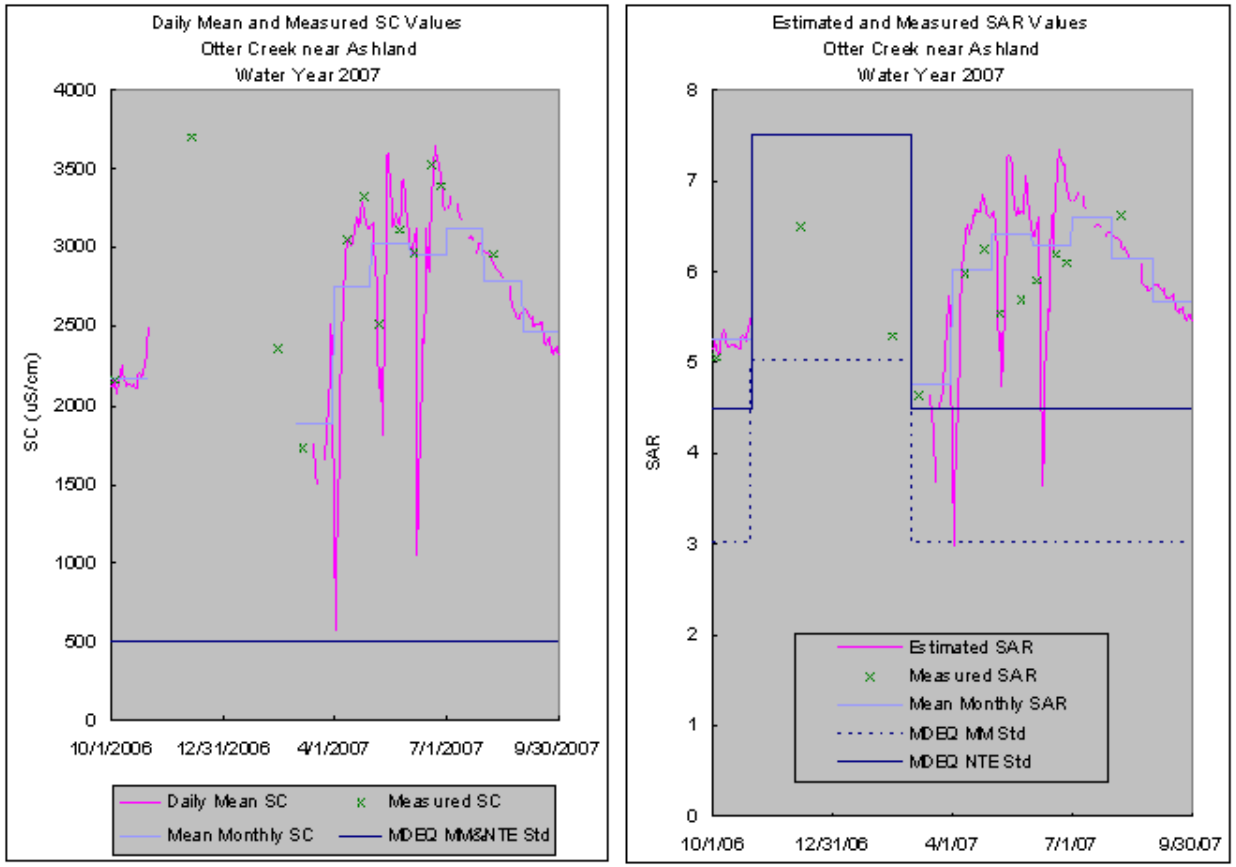


Figure 54 shows daily mean and field measurements of flow in a time series plot for water year 2007 for Otter Creek near Ashland, MT. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 0.2 to 212 cfs. Cumulative 2007 flows were 103% of historical.

Figure 55: Otter Creek at Ashland, MT



A **B**

Figure 55 shows analytical and daily mean SC (A) and analytical and daily mean estimated SAR (B) values in time series plots for water year 2007 for Otter Creek at Ashland, MT. Mean Monthly SC and SAR values are also shown. SC values ranged from 580 to 3700 uS/cm. SAR values ranged from 3.0 to 7.3. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. SC values were in excess of the EC standards for the entire year. Measured and estimated SAR values were above the SAR standards for most of the year.

Figure 56: Otter Creek at Ashland, MT

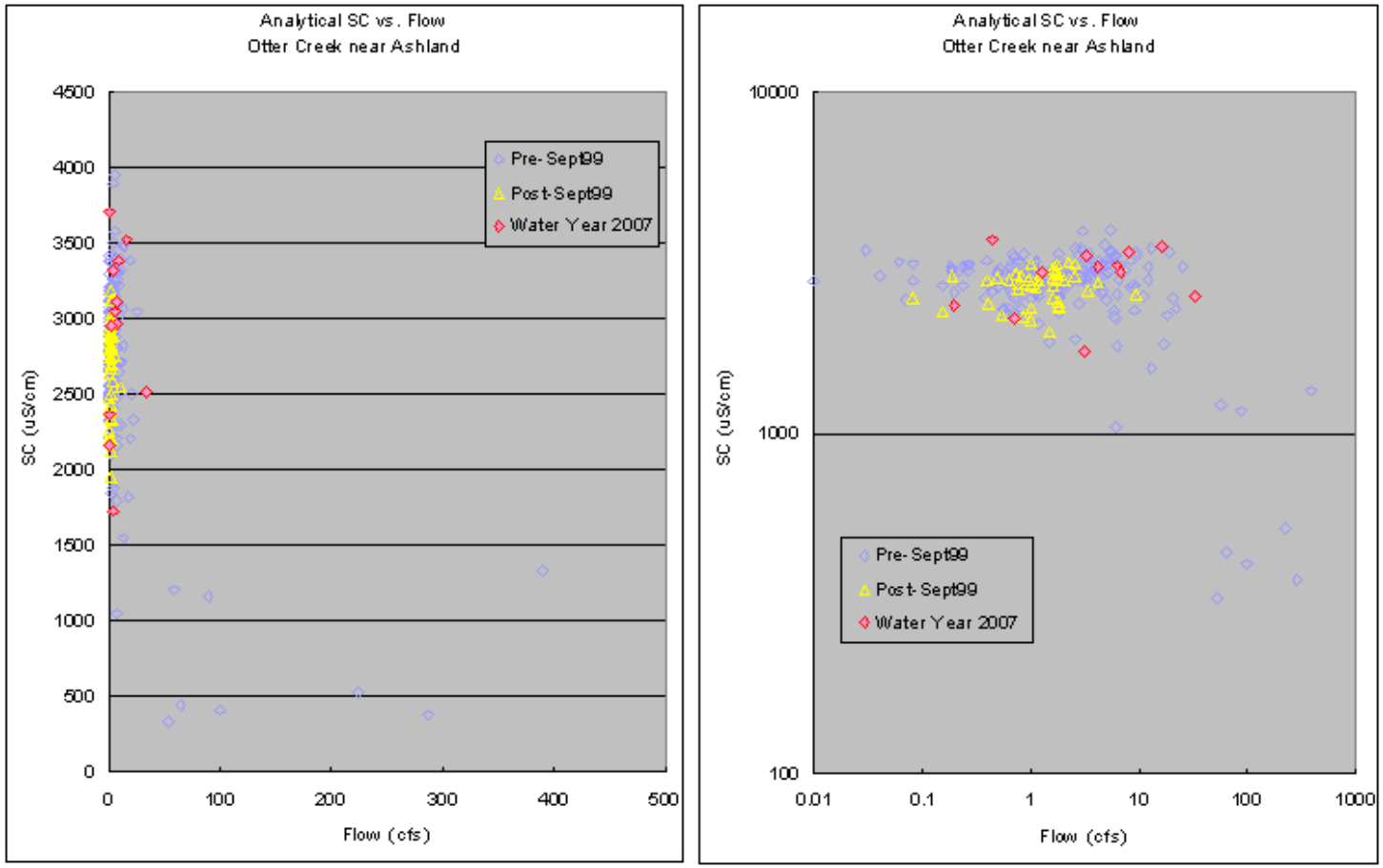
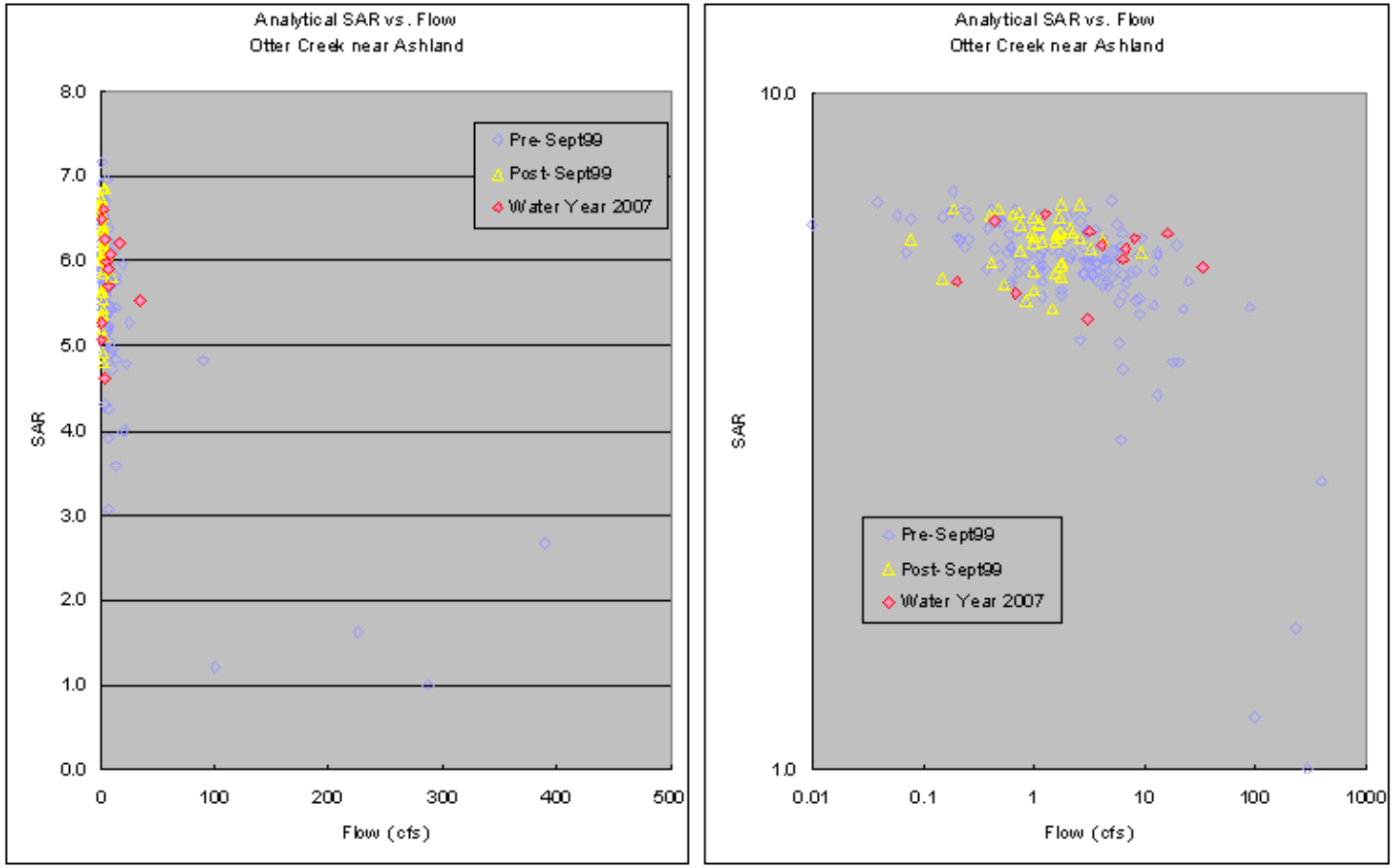


Figure 56 shows analytical SC vs. Flow data for water year 2007 for Otter Creek at Ashland, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 57: Otter Creek at Ashland, MT



A **B**

Figure 57 shows analytical SAR vs. Flow data for water year 2007 for Otter Creek at Ashland, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 58: Otter Creek at Ashland, MT

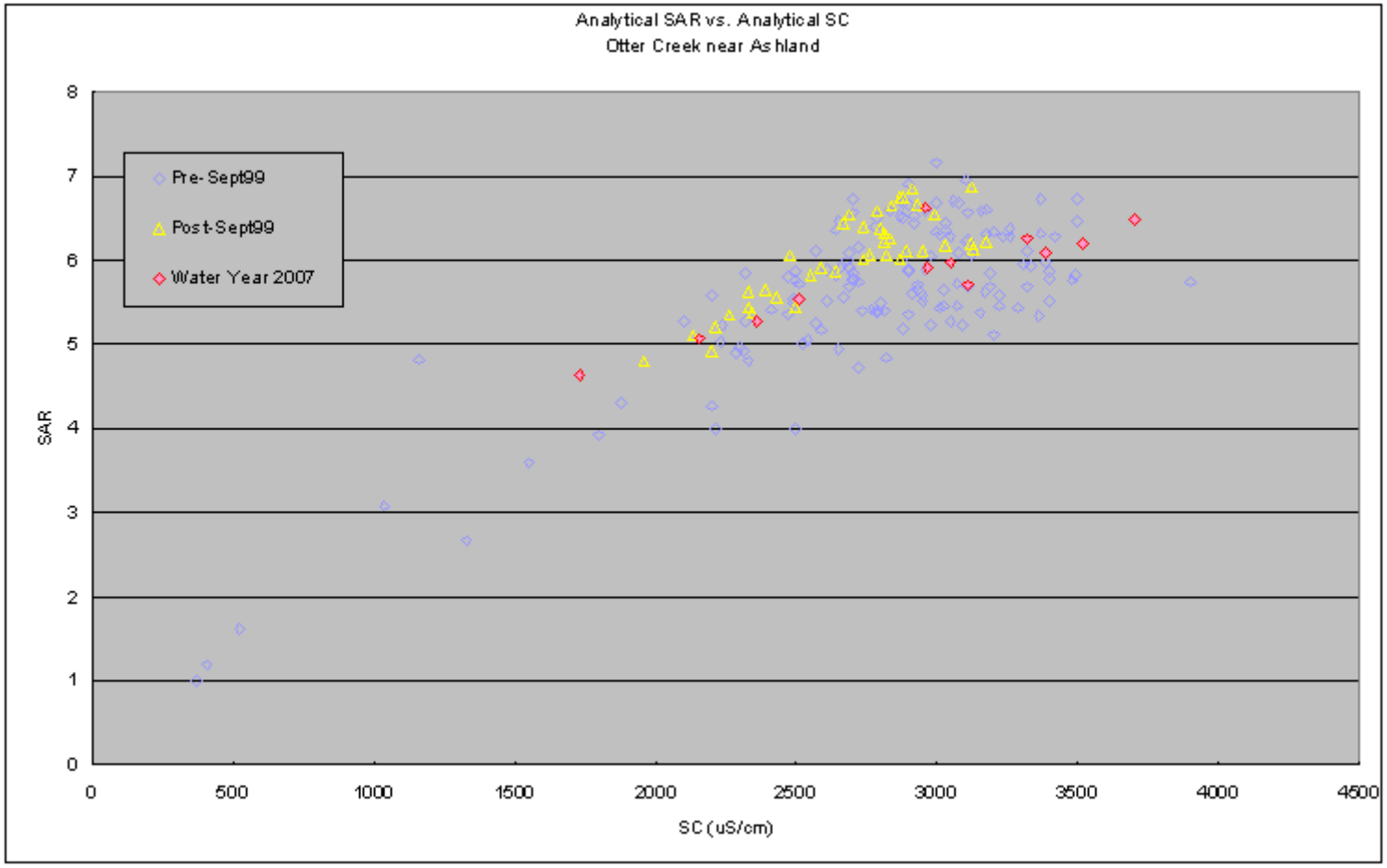


Figure 58 shows analytical SAR vs. analytical SC data for water year 2007 for Otter Creek near Ashland, MT. Historical SAR vs. SC data are also shown to place the data in context.

Figure 59: Pumpkin Creek near Miles City, MT

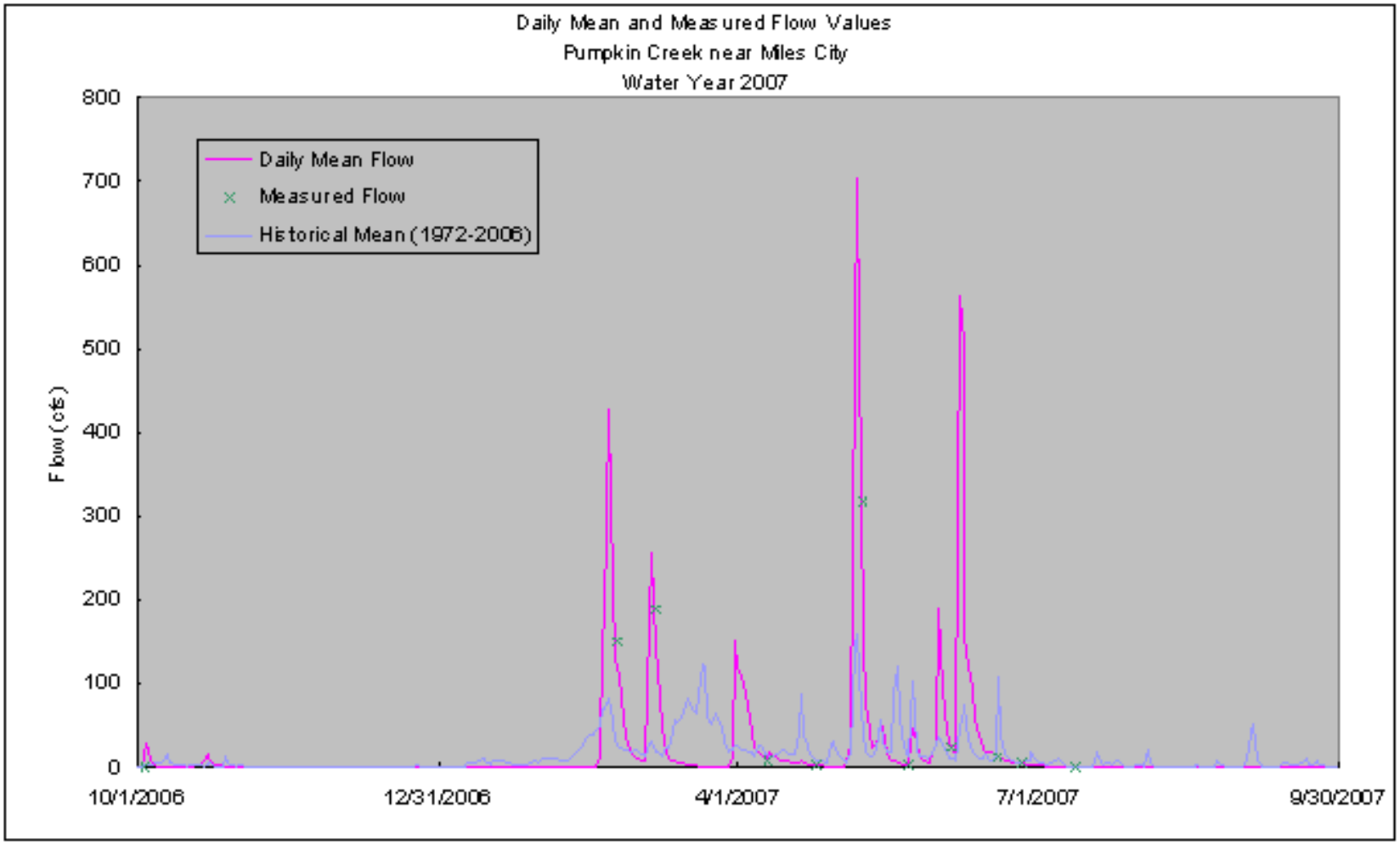
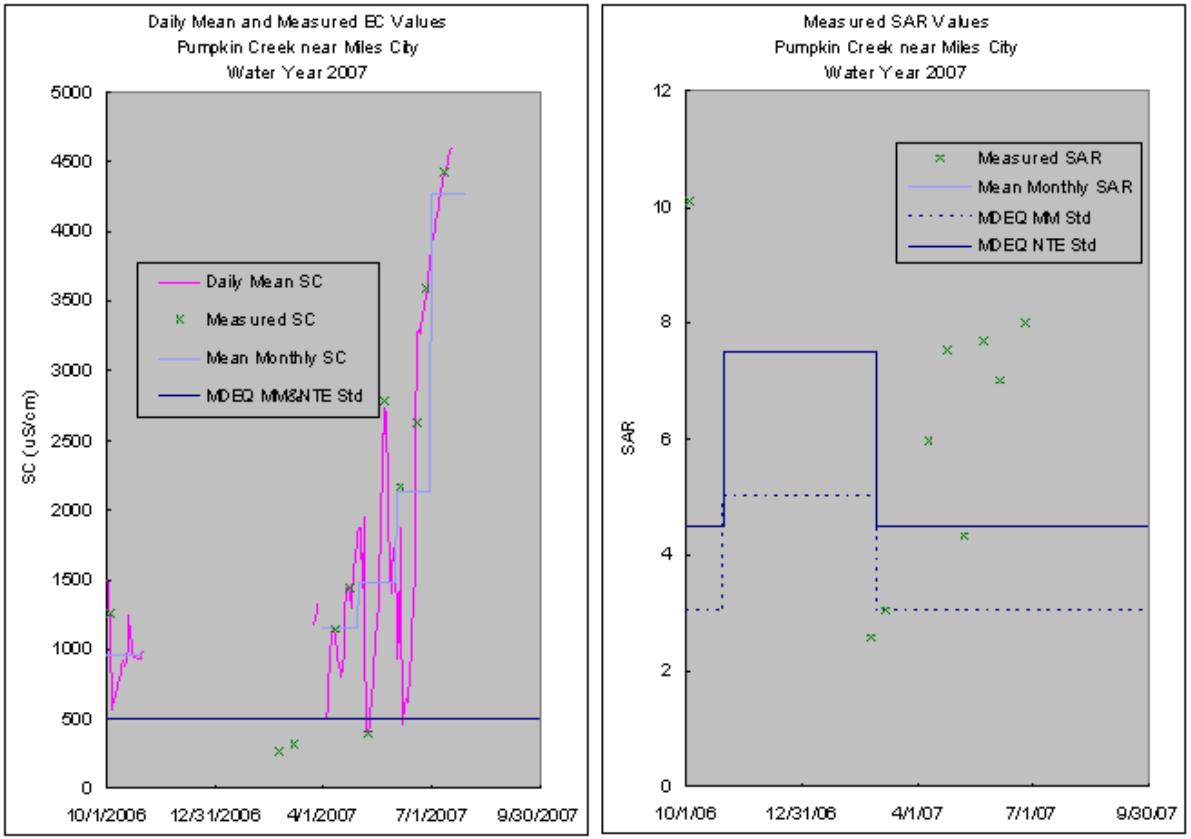


Figure 59 shows daily mean and field measurements of flow in a time series plot for water year 2007 for Pumpkin Creek near Miles City, MT. The historical average daily mean flow values are also shown. Daily mean flow values during 2007 ranged from 0 to 705 cfs. Cumulative 2007 flows were 140% of historical.

Figure 60: Pumpkin Creek near Miles City, MT



A **B**

Figure 60 shows analytical and daily mean SC (A) and analytical SAR (B) values in time series plots for water year 2007 for Pumpkin Creek near Miles City, MT. Daily mean estimated SAR was not determined due to a poor regression relation. Mean Monthly SC values are also shown. SC values ranged from 263 to 4610 uS/cm. Analytical SAR values ranged from 2.6 to 10.4. These values are compared to the instantaneous maximum and Mean Monthly standards developed by the MDEQ. SC values were above the EC standard for most of the year. Analytical SAR values were above the SAR standard for most of the year.

Figure 61: Pumpkin Creek near Miles City, MT

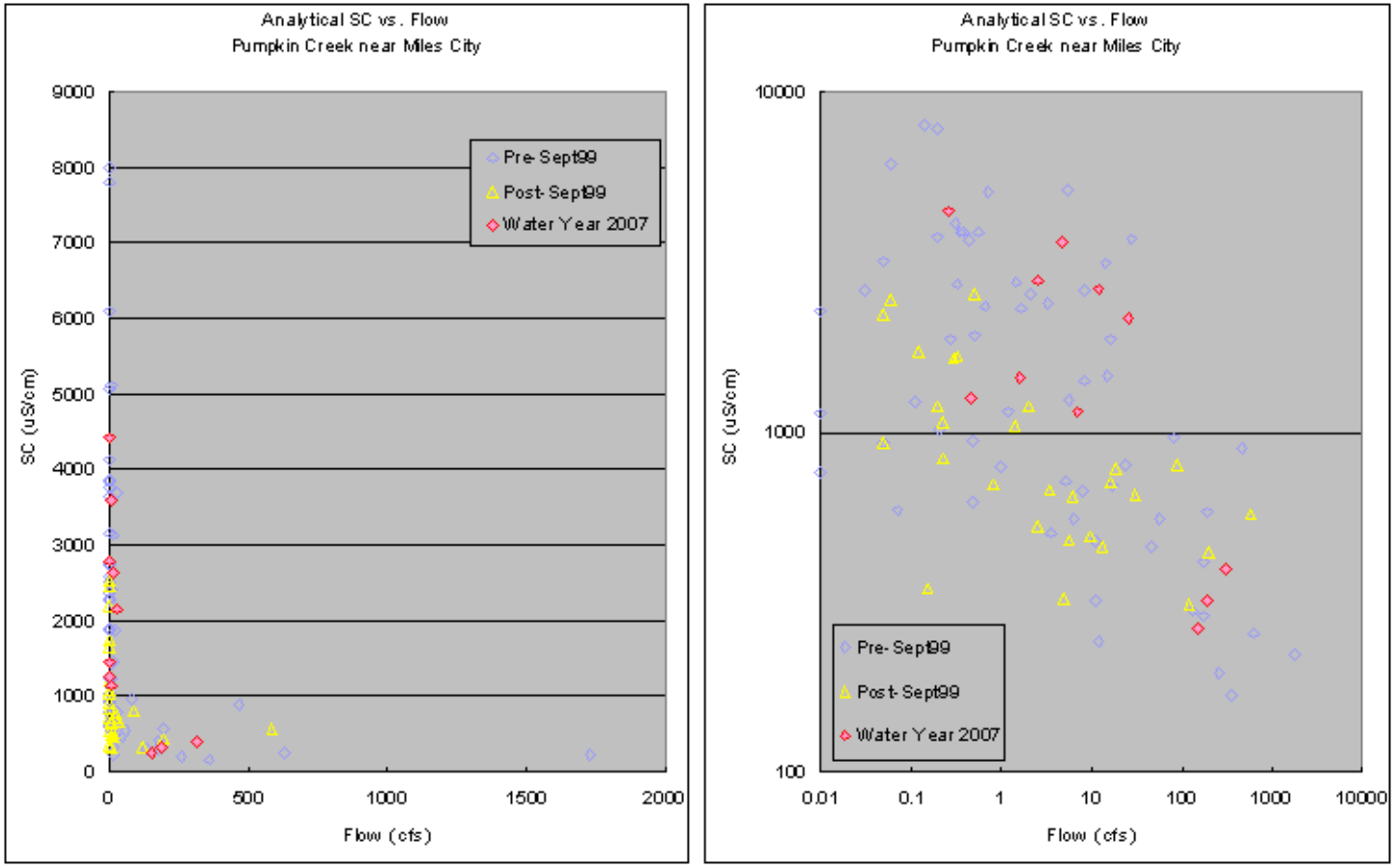
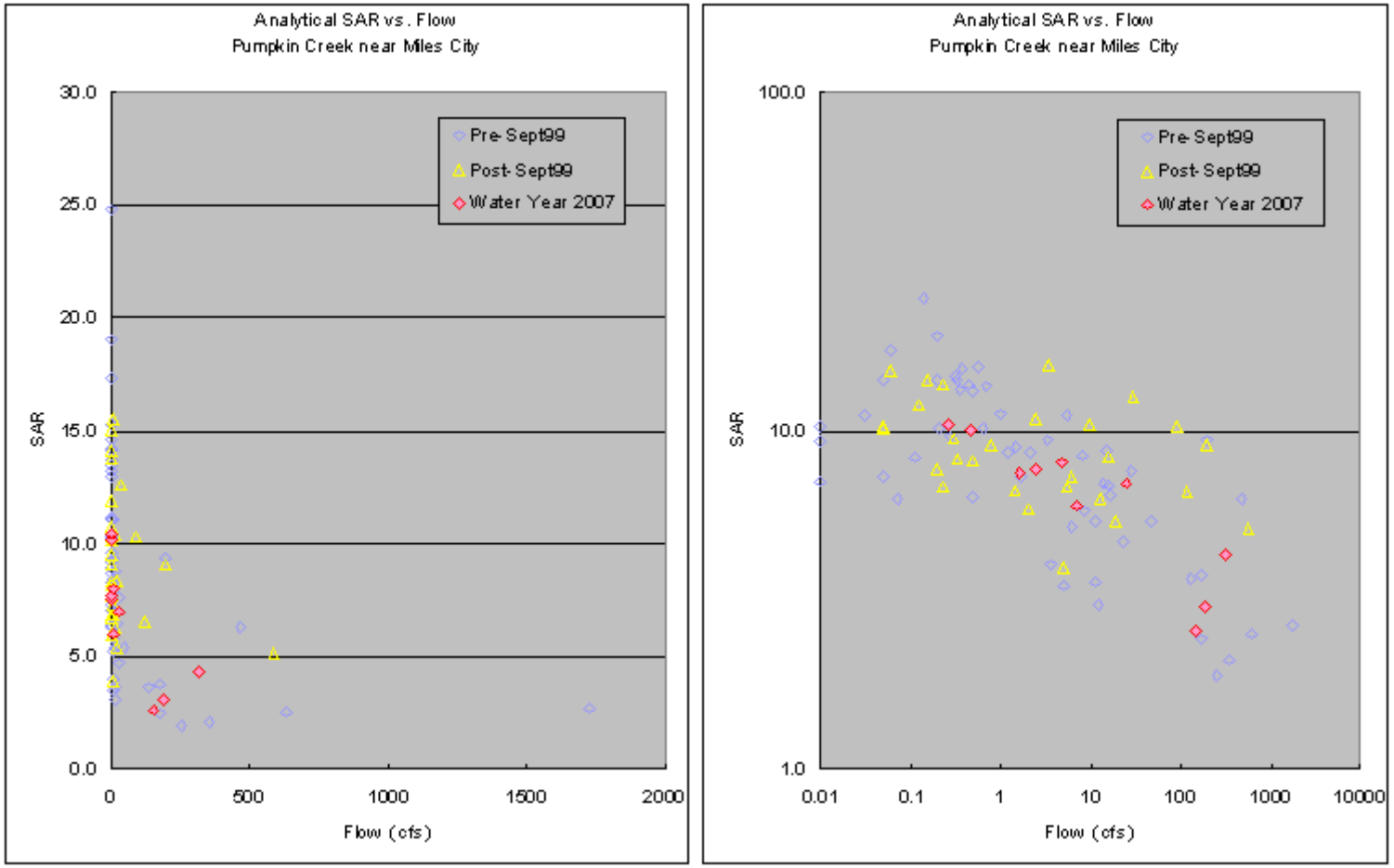


Figure 61 shows analytical SC vs. Flow data for water year 2007 for Pumpkin Creek near Miles City, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SC vs. Flow data are also shown to place the data in context.

Figure 62: Pumpkin Creek near Miles City, MT



A **B**

Figure 62 shows analytical SAR vs. Flow data for water year 2007 for Pumpkin Creek near Miles City, MT. These data are charted on both linear (A) and logarithmic (B) scales. Historical SAR vs. Flow data are also shown to place the data in context.

Figure 63: Pumpkin Creek near Miles City, MT

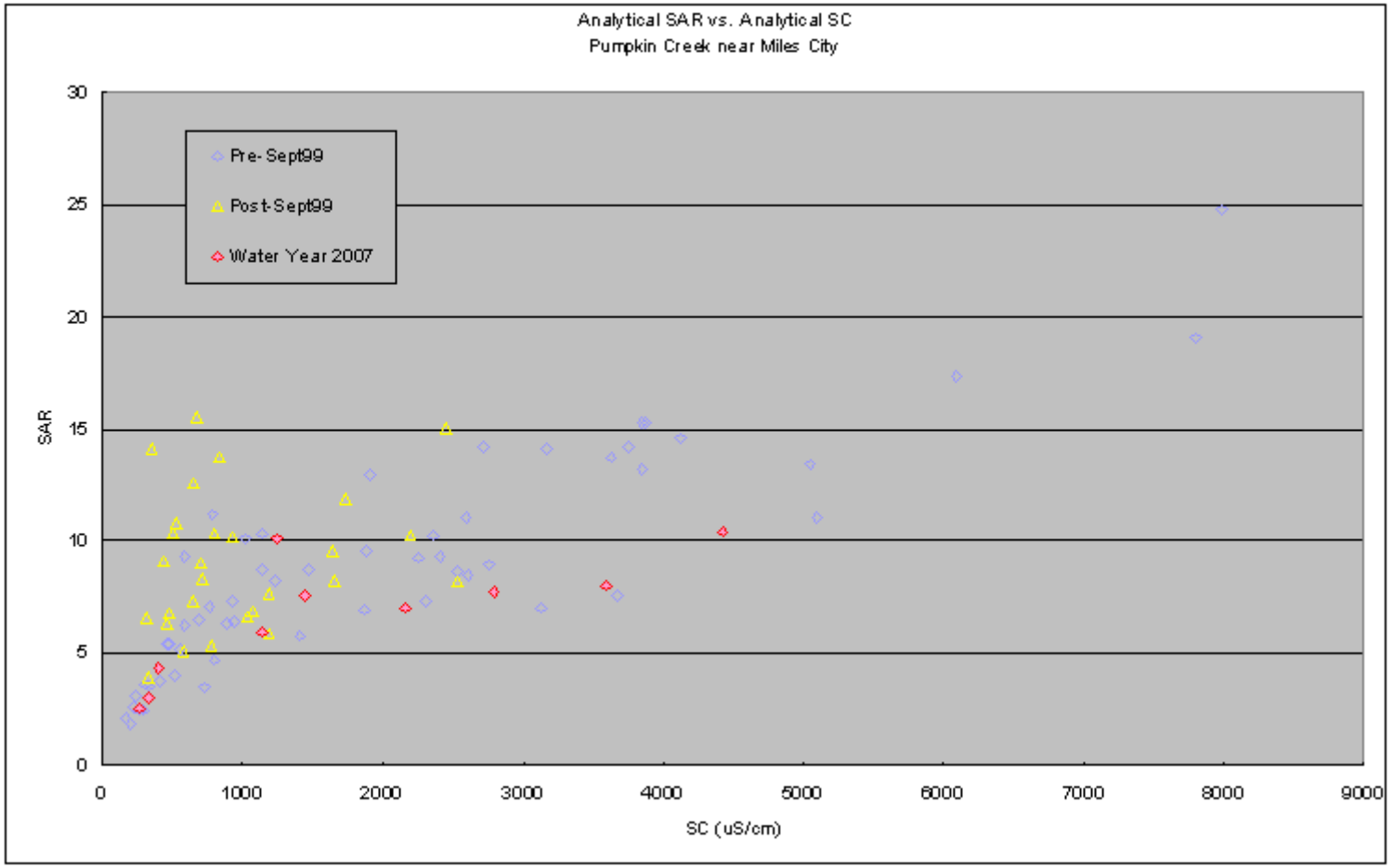


Figure 63 shows analytical SAR vs. analytical SC data for water year 2007 for Pumpkin Creek near Miles City. Historical SAR vs. EC data are also shown to place the data in context.